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MANAGEMENT FACTORS AFFECTING RESEARCH AND EXPLORATORY DEVELOPMENT

Arthur D. Little, Inc.

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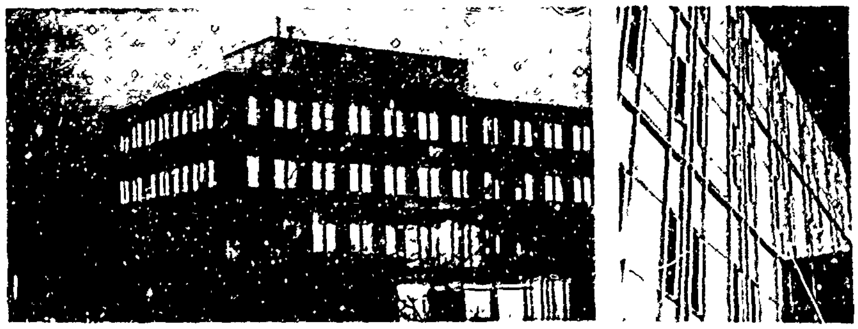

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I. SUMMARY

A. STATEMENT OF THE PROBLEM AND METHOD OF APPROACH

The Department of Defense is vitally interested in obtaining the greatest possible return from the investment it makes in research and exploratory development. There are many aspects of this problem. This study explores one, the effect of environment, in an attempt to develop hypotheses which would assist the Department of Defense to increase its effectiveness in the administration of research and exploratory development.

The primary objective of this study is to discover circumstances which the Defense Department could manipulate or control, and which favor the initiation, execution, and utilization of research and exploratory development projects. In the term <u>environment</u> we include all circumstances which might influence the initiation, execution, or utilization of the work. We have directed most of our attention, of course, to those factors which might be used constructively as tools in the management of research and exploratory development.

The projects we have considered are idealized as research and exploratory development Events (abbreviated as RXD Events, or R Events, or XD Events, as the case may be). We conceive of an RXD Event as a period of technical activity with a well defined outcome. One of its attributes is that it involves some creative or innovative act; another is that it produces an irrevocable or irreversible change in the state of knowledge, in the understanding of what is feasible or how something can be done. This outcome must be such that the RXD Event influenced the development of a weapon system. The outcome may be a progress report, a proposal, a journal article, a patent disclosure, or some other document which summarizes the information generated in the RXD Event; it may also be a verbal presentation, a successful execution of a field test, a consensus in a committee meeting, or some other action not ordinarily conceived of as information-bearing or information-transmitting. The outstanding quality of the outcome is that it is the dividing point between the state of knowledge before the RXD Event was completed, and the state of knowledge after the RXD Event was completed. An extreme test is whether the knowledge contained or derived from the RXD Event would be preserved and propagated from that point onward without any further contribution from its protagonists. An example of an RXD Event is described on page B-6, Appendix B.

The ultimate criterion for selection of these particular Events was utilization in a weapon system procured by the Defense Department for operational use. In other words, a particular Event was included in our sample only after we verified that some operational weapon system was made possible in part through the availability of knowledge evolved by the particular Event.

Most of the research and exploratory development Events were identified in historical studies of six representative weapon systems[1] chosen by the Department of Defense. No attempt was made to produce a complete list of such Events since certain important areas of research, such as nuclear warheads, were off limits by virtue of security restrictions. Instead, the purpose was to develop a list sufficient to explore the methodology of uncovering such Events, and to provide a reasonable base for study of various types of research and exploratory development environments. It was evident that most weapons systems are an outgrowth of a broad activity in research and exploratory development extending over a period of many years.

Eighty-seven Events were identified (see Appendix C for details), of which we describe 11 as Research, 59 as Exploratory Development, and 17 as Advanced Development. The latter were included to provide some test of the line of demarcation between Exploratory Development and Advanced Development. A sample of 63 Events, including all 11 Research Events and 52 Exploratory Development Events, was selected as a basis for further environment studies. These Events took place at 36 different laboratories of the following types:

Government Laboratory (3)

Government Laboratory-University operated (5)

Government Laboratory-Industry operated (1)

University (2)

Industry (24)

Research Institute (1)

We gathered no control samples of unutilized research and exploratory development nor of research and exploratory development projects that were "failures."

Two methods were used to uncover research and exploratory development Events. One consisted of beginning with a development utilized in one of the six selected weapons systems and tracing it back in history toward its exploratory development and research phases. The second method was to start with a research Event and trace forward the ensuing developments into possible weapons system use. Both methods required extensive reading of reports coordinated with interviews of Department of Defense and laboratory personnel, since no weapons systems histories existed which contained information of this sort.

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1. Mark 46-0 Torpedo, XM 102 105MM Howitzer, AGM-28 Hound Dog Missile, Polaris Missile, Minuteman Missile and Sergeant Missile

Both methods resulted in uncovering a predominance of Events of an exploratory development rather than a research nature. We believe there are two reasons for this. First, most of the many developments which go into making a new weapons system possible are triggered by the needs and operational requirements of such systems. The ideas utilized in the solution of these needs are of an innovative type and the resulting work is usually characterized as exploratory development in nature rather than research. There were few cases of scientific breakthroughs apparent in the systems studied to date. Secondly, while it may appear to be logical that the aforementioned exploratory development is easily traced back to the specific research knowledge upon which the innovator based his reasoning, this is not the case. All too often such basic knowledge and understanding had become generally available in the text books, and the innovator usually had absolutely no idea what specific bits of knowledge he tapped or who had evolved this knowledge.

We believe that studies of other weapon systems would also uncover more exploratory development than research. Therefore, this study is (and others like it would be) heavily weighted toward a study of exploratory development environment. These few cases of research have led us to believe that research environments differ from exploratory development environments. We have therefore treated the environments of research Events independently from those of exploratory development Events.

The following sections describe a number of findings and recommendations based on these environmental data. Most of them are based on the 52 environments of exploratory development Events alone, although many of the statements would not be much different if they were based on all 63 environments. Those findings peculiar to research environments are treated later, although some references to research and others to the total population of research and exploratory development are made from time to time where it serves to make the results easier to understand.

A task implicit in this study was the determination of what is meant by environment. Initially, our investigations were directed toward objective, quantitative, static factors such as type of institution, educational background of participants, pattern of funding, mechanism of reporting, and so forth. However, as this list was gradually extended, it became obvious that any description based only on such factors would be incomplete and would fail to show significant relations implicit in our data. We therefore found it desirable to introduce terms and concepts from the behavioral sciences, and to deal explicitly with motives, attitudes, and the processes of human interaction.

We have found it especially important to distinguish between two contrasted systems of management and control: authoritarian systems based on a static hierarchy with well-defined levels of authority and chains of command; and adaptive systems with diffuse authority and responsibility, with communication through a broad network, authority based on wisdom and experience rather than organizational status, and implementation by consensus rather than by decree. The associated terms used to describe types of inter-personal and inter-group relations usually found with these systems of management and control are coercion-compromise and consensus-collaboration, respectively. Each of these terms characterizes an environment with many inter-related features. They are explained further on pages I-16 and I-18.

While each of these systems has particular utilities, a major thesis of this report is that research and exploratory development thrive in adaptively organized groups enjoying consensus-collaboration relations with their sponsors.

Finally, we have two warnings to issue. First, the data obtained in this initial study represents a limited sample, so that findings only, not definitive conclusions, can be drawn. Second, many opinions and prejudices exist with respect to proper methods of administration of research and development, and we hope we have prevented our own from affecting the course of this study.

B. FINDINGS AND RECOMMENDATIONS CONCERNING EXPLORATORY DEVELOPMENT ENVIRONMENT

Our most detailed findings concern exploratory development because most of our RXD Events are more typical of exploratory development than of any of the other categories of R&D recognized by the Defense Department. The Department defines exploratory development as follows:

> Exploratory Development (6.2) - Includes all effort directed toward the solution of specific military problems, short of major development projects. This type of effort may vary from fairly fundamental applied research to quite sophisticated breadboard hardware, study, programming, and planning effort. The dominant characteristic of this category of effort is that it be pointed toward specific military problem areas with a view toward developing and evaluating the feasibility and practicability of proposed solutions and determining their parameters. Program control of the exploratory development element will normally be exercised by general level of effort.

The principal findings and associated recommendations are set forth on the following pages. Most of the findings are illustrated and illuminated with statements by experienced managers and quotations from the literature. Quotations matching or contrasting with certain of our findings have been hard to find. We believe that these findings either are new or are expressed in a novel way.

LITERATURE FINDINGS

There is also today a tendency to let the spectacular aspects of some kinds of technology lead us to give undue attention to those things which are glamorous, at the expense of those things which are important and badly needed. As we push ahead with the military uses of outer space and the advanced technology of space science and exploration, as indeed we are and must, and as we pursue glamorous technological objectives in other fields, let us not forget that we have vitally important, if less spectacular, programs in military technology and in science that must not be downgraded in the emphasis we give them and in the top-flight manpower we assign to them.

I do not imply that we should be any less bold or audacious, any less far-reaching and creative in our technology. I do suggest that we have problems of common-sense priority and funding and use of scientists and engineers which require disciplined judgment in our planning and in establishing requirements. Research, especially applied research, can help provide the critical analysis necessary to define meaningful priorities. (J. R. Killian)

Successful products are not so much the results of good ideas but of one man's determination to make them succeed. (General Dornberger)

Genius is one percent inspiration and 99 percent perspiration. (Thomas A. Edison)

The full fruition of scientific work depends upon three things: the desire to know, the initiative to find out, and the awareness to apply. (Sir Cyril Hinshelwood)

Innovation is the basic function of management, whether of industry, politics, science or the arts, and management must coax or coddle it into being. (William T. Brady)

The complexities of nature will always limit man's knowledge to a smattering of truth. Science advances by the slow attrition of ignorance and by the constant recognition of its uncertainties. (Henry DeWolf Smyth)

1. Most RXD Events Result in Modest Innovations

When this study began, many people believed that weapon system development depended on a succession of "key events" and important technological and scientific breakthroughs. The evidence gathered from the six historical surveys we have undertaken in our study show that this is probably not true. The innovations resulting from our 52 Exploratory Development Events were modest; however, they did make an important contribution to the value of the weapon system in which they are used.

In most cases the innovations interact and reinforce each other. The resulting improvements in performance, operational utility, and cost cannot be attributed to one innovation only, because the benefit from exploiting each innovation depends on exploiting others at the same time. For instance, the high search rate for the Mark 46 torpedo guidance system is only useful because of the high speed of the vehicle. This was possible only because of several innovations introduced in the fuel and motor, which in turn put requirements on the propellor, on hydrodynamic noise reduction, and on signal processing. These made other innovations both necessary and useful, and when they were achieved, a vastly improved torpedo resulted. But each Event, taken individually, is not a major technical breakthrough or key idea.

Of the several hundred ideas we have examined in the backgrounds of six weapon systems, only two, both Research Events, could be considered key ideas or major technical breakthroughs: the invention of the transistor and the development of a high temperature shock tube and resulting advances in gas dynamics. We infer that the major effort in exploratory development is probably not for key events and important technical breakthroughs but for a very much larger number of significant but individually modest innovations.

Recommendation

Any program for improving the management of exploratory development resources must show substantial interest in and concern for modest innovations. The Department of Defense must encourage their initiation, execution and utilization, and must recognize the interrelations among such innovations and military needs.

THE LABORATORY DIRECTOR

Literature Findings

The research director is the most important single factor in the success of the laboratory. He must not only set the tone of the laboratory through the acquisition, inspiration and encouragement of its staff, but must also work with top corporate management. As one of those most responsible for long range corporate success, he must be one of the top management team responsible for the establishment of corporate plans and objectives. Only top management has the over-all understanding and power to set levels of risk and to implement plans. (B.S. Old)

Research is related to every facet of the business. Corporate policy and research policy must go hand-in-hand, and anything short of responsibility for research at the top of the organization is a dangerous dilution of effort. Management needs to know what research is being done, and why, and generally how. A good deal of research operates on the hairline of success or failure; management is the fulcrum. (E.N. Funkhouser, Jr.)

Maximizing creative output is probably the most important day-to-day task of the research manager. The success of organized research is due to the fact that the organizations have been built up and are controlled by scientists. No one organization arrangement is best for all purposes. Each case deserves special consideration to determine how the work should be organized. (W.D. Lewis)

Any laboratory which is built around the dominance of its director, however gifted and benevolent he may be, is ill prepared to cope with its future. The best thing a director can do for a research institution is so to shape it that he is not necessary to its vigorous continuity. (Ralph Bown)

Time is a resource like money, raw materials or facilities; it flows on inexorably and once expended cannot be regained. We have the option of investing it wisely or squandering it extravagantly. We cannot be certain, but prudence makes us assume that our opponents are not squandering time extravagantly; we must make sure our investment of it is sound. As research directors and administrators, we may not play the part we once did in invention, innovation or discovery, but we can do one thing of unique importance. We can bring technology into communication with its environment sooner than the entrepreneurs and planners of the economic social and political world. It is up to us to try. (R.E. Gibson)

It is a rare individual who combines all the attributes necessary to becoming a successful research director. (Merritt Williamson)

2. The Environment is Strongly Affected by the Laboratory Director

Most (46/52)* of the directors of laboratories in which the Exploratory Development Events took place were ranked by us as good or excellent in capability. In general, these laboratory directors were men characterized by breadth and depth of technical insight, by previous technical accomplishment which afforded them stature in the technical and scientific community, by skill in communicating with and motivating subordinates, by aggressiveness and imagination in the promotion and pursuit of objectives which inspired confidence in sponsors. Without doubt we confirm the lessons stated in the literature to the effect that the director is a major factor in the success of a laboratory. He is in a good position to maintain the type of environment desirable for exploratory work; most of the recommendations in this report can be encouraged, implemented and supported by the laboratory director.

One attribute of the good director is the ability to keep alive and nurture ideas. In all but a very few cases, the research directors had succeeded in building an environment such that the innovator reported no difficulty in either selling his idea to his superiors or in proceeding on his own, depending on his position in the organization. Furthermore, the environment was such that the innovator received encouragement, and through various means had funds made available to him, because the value of the project was recognized by the appropriate people within the organization.

Another characteristic of the outstanding director is the ability to sell the developments of his laboratory. In many of the cases noted in this study, the director was actively engaged in such selling, and usually his reputation was such that his judgment was respected by the Department of Defense.

It should be noted that in certain Department of Defense laboratories, even the outstanding directors complained that they felt remote from "top management" in the Pentagon. This was given as the reason for the departure of some such individuals from Government service.

Recommendations

The Department of Defense should give weight to the reputation of the laboratory director when allocating exploratory development resources. It should consider training programs for developing those scientists in its own laboratories who have management potential, as well as means for attracting as laboratory directors promising young men from outside Government circles.

In addition, it seems clear that despite the difficulties involved, improved communication of plans, requirements, and objectives between Department of Defense "top management" and in-house laboratory directors must be sought.

*The actual number of cases in our limited sample is shown as the numerator of a proper fraction; the denominator is the size of the sample, usually 11 R Events, 52 XD Events, or 63 R&XD Events; e.g., 46/52 means that the statement was true for 46 of our 52 Events.

LITERATURE FINDINGS

If you do not expect to be in business five years from now, there is no need for expenditures for scientific research. (G. Guy Suits)

Government, business, and industry are dependent.....not alone on technology but on an accelerating growth of knowledge deriving from research that once was sometimes described as "pure." (Glenn T. Seaborg)

The application of science can be directed to produce results of value; the creation of science proceeds from the free operation of the minds of scientists. (C.E.K. Mees and J.A. Leermakers)

Yet with all this, I would still say that the prime need in modern technology is for wiser, smarter thought and action about what we have, rather than reliance on a headlong hunt for miracle solutions, or brute-force, extravagant effort to find what we do not have. I would still say that the most significant impact of science on our technical systems will come from better methods for studying and layout of what choices really exist; and for differentiating between what we know and what we can merely guess. (F. R. Kappel)

Thus, inevitably the key issue is management of the total research resources, not the management of specific research programs even though that too, is gravely important. The mainspring of the issue is in selection of courses of action which can have a major impact on an institution, based on full recognition of the part research and development can play, a willingness to recognize that such a major impact involves real risks, and finally the selection of the specific R&D programs which can bring success to the strategy. (P. E. Haggerty)

One of the first things a research institution needs is a technical or scientific objective. Only by having some reasonably well defined goals can researchers make those choices which they face at every turn as to which of several possible lines to follow. This statement does no violence to the classical concept that true research is without restraint and follows the intellectual curiosity of the researcher. (Ralph Bown)

If there is any one aspect of the subject which deserves particular prominence, I believe it is that of choosing the right definition of mission for an R&D enterprise. To make the right choice, and then to adhere to it, may not be as easy as it sounds. For example, one may have to decide rather frequently whether entrance into a new field is, in fact, compatible with the long term objectives of the organization. We have occasionally, in the past, had the even more wrenching experience of withdrawing from promising areas in which we were already well established because they threatened to lead us too far away from our primary objective of providing even better communication service. However, such mission definition is necessary if the organization is to develop the "enduring themes" and flow of technology which I have described. In the long run, it is the best means of giving the organization continuing purpose and vitality. (James B. Fisk)

3. Investment Strategies

We have enough background information to infer investment strategies underlying most of the Exploratory Development Events (33/52). One strategy was observed 17 times:

- Invest in fields characterized by rapid change, continuing interest to weapons technology, and a relation to a clear current need for weapons improvements.

Six other broad strategies were seen two to five times each:

- Invest in research and development institutions characterized by a record of accomplishment, facilities well matched to the work to be done, access to university resources, an objective approach to alternate solutions, or a director whose dynamism inspires confidence.
- Invest in men of distinguished accomplishment in the field of interest.
- When the need is clear, support evaluation work on all ideas which show even remote promise of meeting the need.
- Allocate some discretionary funds to a large class of research and development institutions, recognizing that creative ideas occur at random, that broad awareness of military needs will promote productivity, and that the capability to evaluate randomly occurring ideas promptly is desirable.
- Force technological progress by attempting to develop a weapon system even though advances in a number of areas will be essential to success.
- Focus exploratory development effort by clear statements of weapon system performance requirements, but let technological advances pace system development effort.

In most Events (33/52) the boundaries among Research and the various classes of Development were blurred; in most (33/52) some idea, stimulus, or information was derived from a less basic development, production, or operational program; and in a substantial number (11/52) the Event was initiated after the beginning of system development of one of the systems in which it was used. Interdisciplinary stimulation influenced most of the Events (29/52) and even more (36/52) were in fields of science or technology which were rapidly changing at the time.

Recommendation

The Department of Defense should continue to devote attention to the formulation and improvement of strategies for research and exploratory development investment. Administrative and fiscal distinctions among Research and various categories of Development should not discourage mutual stimulation and support. Exploratory development resources should be made available to respond to problems arising in advanced development, operational system development, and use of materiel. The Department should not constrain research and exploratory development by partitioning its resources among fields defined so as to be static and mutually exclusive, but should adapt to interdisciplinary activity and to uncertain and changing boundaries among fields.

LITERATURE FINDINGS

A company's way of handling new ideas has a critical effect on the quality, novelty and daring of ideas its staff members will offer. This effect, like feedback in an electronic circuit, can work to stabilize the typical output of the organization or it can work to neutralize or disrupt its functioning depending on the way management's actions are perceived by the research workers. (W. C. Lothrop, S. Kingsbury, L. W. Bass)

One particularly important personal characteristic in research leaders is intellectual generosity. In a field where fruitful ideas are a major measure of a man's worth, a research leader must be prepared to help others find gold, to steer them away from fool's gold, to leave people alone or to guide them on the basis of a shrewd assessment of brains and personalities. (W. H. Sebrell)

In practice, one of the most difficult tasks of a laboratory director is to overrule an investigator, even if the director is convinced that the investigator is digging in an exhausted vein for the sake of digging. The batting average of the laboratory director in making these decisions - and the skill which he displays in having people accept his decisions - are a major measure of his effectiveness. As the laboratory ages, these decisions must be made more often, unless the laboratory director is exceptionally lucky. (W. H. Sebrell)

The scientist in the applied or developmental field is simultaneously lashed by necessity and stimulated by rewards. He is challenged by competition, disciplined by deadlines, judged by results - and he thrives and produces. (H. Work)

Seeing field use allowed the engineers on Corporal to think of ways to improve on the basic mission. (R. J. Parks, concerning the origin of the Sergeant system)

4. The Stimulation of Technological Advance

In nearly all Events (49/52) the burst of successfully utilized activity constituting the RXD Event started only when the following three elements were present:

- An explicitly understood need, goal or mission.
- A source of ideas, typically a pool of information, experience and insight in the minds of people who could apply it.
- Resources, usually facilities, materials, money, and trained and experienced men, who could be committed to do a job.

These three elements can be brought together in various time sequences; the last member to be joined to the other two (or one) can be regarded as the "trigger" for the RXD Event activity. The following triggers each occurred in about one-third of the Events studied:

- The allocation of resources to look for ideas in order to meet a recognized need (16/52).
- The occurrence of an idea or an invention which met a need, using available resources (22/52).
- The recognition of a need, which could be met by available ideas and resources (14/52).

The trigger usually comes some time after the other two elements have been joined; the median delay is one or two years, but the spread is broad. Regardless of the time delay and the order of the sequence, the initial activity in the RXD Event was nearly always done at the place where the idea was generated (47/52). In about half of the Events (27/52) a more specific understanding of a need, goal or mission was disseminated after a more general expression had already been widely recognized; in nearly all of these (25/27) the RXD Event was responsive to the more specific need. It is notable that this was true in many cases when the recognition of the need was not the trigger.

These RXD Events have not promptly exploited available scientific and engineering background. Except for the innovation in the RXD Event itself, the technological base usually had existed for several years before the Event. The spread of time delays was broad, with a median time of five years for exploratory development and three years for research. This delay indicates a reserve of scientific and engineering knowledge which is not being fully used.

Recommendation

Of the three ways to trigger exploratory development activity, the Department of Defense at present systematically exploits only one: allocating resources to look for ideas in order to meet recognized need. The Department should also exploit the other two. First, they should support environments which foster creative inspiration, have resources available to exploit new ideas, and can commit those resources rapidly after exploratory effort and some initial evaluation. Second, the Department should spur the advance of weapons technology by better anticipation of its needs, and better dissemination of these needs to scientists and engineers with a good command of current technology, who operate in an environment conducive to creative work, and who can command resources to evaluate and execute their ideas. In any case, they should encourage the conjunction of the three essential elements: need, idea source, and committable resources. Wherever possible, general needs should be reinforced with statements of specific need; however, the Department should avoid the trap of proposing a solution or a method of approach. The Department should avoid transplanting ideas for research and exploratory development at an early stage; instead, it should support initial efforts where the idea is generated.

THE IMPORTANCE OF FREEDOM OF CHOICE

Literature Findings

The way an industrial laboratory can achieve a well-balanced research program in trying to solve practical problems of business is to delegate the decisions on work choices, insofar as possible, to the people who are actually doing the work. There are many reasons for this, and one of the most important reasons is that it is only those people who are qualified to do the work who know enough about it and its applications to be qualified to make the choices; choices in general are made at the forefront of knowledge. This is a basic and simple concept with which it is difficult to disagree.

If the man at the working level is really part of the organization and has the interest of the company at heart, and he has the authority and responsibility to make his decision and know that he can follow his own course to justify his own actions, then the company will benefit to the maximum. (Ralph Bown)

Freedom in the choice of problems subject to the criteria of relevance; freedom to carry a study out to the point of demonstrating the merit of an idea - these freedoms should not be thought of as inherent natural rights of individuals - they are to be earned over time by distinguished performance. (J.B. Fisk)

Depending upon the mission and nature of the work of the particular laboratory, a fraction of the annual laboratory budget shall be set aside for work judged by the laboratory director to be of promise or importance without need of prior approval or review at higher levels. The results of this work shall be reviewed by the Assistant Secretaries for Research and Development of the Military Departments. (Robert S. McNamara)

5. The Importance of Freedom of Choice

The decision to initiate work was made locally in most Events (41/52). In only a few (4/52) was the Event conceived by its sponsors and transmitted in a formal document such as an RFP; in most Events (46/52) the understanding of the need was passed on informally rather than by a formal document.

Most of the Exploratory Development Events (31/52) were carried out by teams of people, none of whom had distinguished professional reputations at the time.

In most cases some of the protagonists were familiar with military problems. They had no problem in selling their idea within their local organization even though its value may not have been recognized in its early stages in more remote parts of the Defense Department.

Most Events (41/52) were supported initially from discretionary funds, funds already allocated for broadly defined related work, or funds diverted from related activities; a much smaller proportion (11/52) had funds specifically set aside for the Event activity or specifically approved after the idea for the Event was brought forth. It is interesting to note that in four of the five Research and Exploratory Development Events where work was supported by funds requiring prior specific approval by the Department of Defense after the idea was generated, it was reported that delays of six to twelve months occurred before resources were allocated. On the other hand, in all three privately funded Research and Exploratory Development Events requiring prior specific approval, it was reported that work was started promptly after need and idea were brought together. During our interviews many contractors emphasize that many of their successes could be attributed to flexibility both of funding and of operation.

We have attempted a rather coarse and subjective evaluation of the degree of speculation which would have been perceived by a reasonably competent observer, prior to the Event, confronted with the decision to invest money and resources in an effort to accomplish the Event. In nearly all Events (49/52) the initial probability of success coupled with the potential value of success to weapons technology afforded overwhelming justification for the commission of resources. Though the finding is biased by the fact that only successes have been studied, the implication is that the initiation of utilizable research and exploratory development most often has not involved controversial investment decisions.

Recommendation

The Department of Defense should consider means for further encouraging flexibility in the use of exploratory development funds at the local level. The initiative for undertaking exploratory work should be exercised by people closely associated with those generating the ideas, such as members of the laboratory technical staff and the laboratory director. Commitment of resources should be prompt, and informal and open communication of needs and of progress toward fulfilling them should be encouraged.

ADAPTIVE AND AUTHORITARIAN MANAGEMENT ENVIRONMENTS

In order to be able to describe systems of management meaningfully but in as few words as possible, we found it necessary to use some terms from the behavioral sciences. Although they are well known in some circles, they may be sufficiently unfamiliar to warrant some definition at this point.

A number of social scientists (Section VII, 3, 7-11) have recently concluded that systems of management belong essentially to two types, each of which is characterized by a rather lengthy list of characteristics as recorded in Tables V-2, V-3, V-4 and V-5 of this report. Each of these authors uses different names for the two types, as shown in Table V-1; we call them authoritarian and adaptive.

Our experience confirms these authors' observations that most particular examples show most of the attributes of one type and almost none of the other; mixed specimens are rare.

An authoritarian management system is characterized by a well-ordered hierarchy. Responsibilities and resources are subdivided into non-overlapping parts and assigned to subordinates, along with the delegation of limited authority. Conflicts and uncertainties are resolved by appeal to a higher level in the organization. Status is defined by rank in the hierarchy, and communication is between superior and subordinate or between peers responsible to the same supervisor.

An adaptive management system is characterized by diffusion throughout the organization of an understanding of objectives and of the responsibility for striving for them. Experience, knowledge, and ability anywhere in the organization are a valid basis for decision-making, which is not the exclusive prerogative of the "head." The actual seat of decision-making depends on the subject matter, and concerted implementation of decisions is the result of consensus. Status and authority are ambiguous, responsibilities overlap, and control and communications flow through a multiply-connected network rather than a well-ordered hierarchy.

As described by Burns and Stalker:

> "A mechanistic [authoritarian] management system is appropriate to stable conditions...
>
> The organic [adaptive] form is appropriate to changing conditions, which give rise constantly to fresh problems and unforeseen requirements for action..."

6. Research and Exploratory Development Flourish in an Adaptively Organized Group

Nearly every (51/52) local environment in which Exploratory Development activities were carried on was adaptive rather than authoritarian. The following non-exclusive factors appear to have encouraged or sustained adaptiveness:

- A philosophic commitment to adaptiveness on the part of the laboratory manager (23/52).
- Laboratory organization by tasks or projects (22/52).
- A rapid growth in the size of the organization, which enhanced fluidity (13/52).
- A dominant adaptive personality (11/52).
- The influence of goals whose importance transcended other considerations (11/52).
- A competitive drive which transcended other considerations (11/52).

The incidence of some of these factors overlap considerably, but the sample is too small to validate significance of any correlations.

Personal commitment was a positive influence in the achievement of success in nearly every Event (47/52) and some form of competition was a positive influence in most (35/52).

A few Events (8/52) were carried out by groups located in organizations generally managed according to an authoritarian pattern, but in nearly all of these (7/8) the group functioned adaptively. Part of their adaptation was to insulate themselves from many of the authoritarian controls in their organization. In only one Event did we find complete permissiveness: those constraints which normally exist in an adaptive management system were nearly always evident (49/52).

Recommendation

The Department of Defense policies should encourage adaptiveness in the institutions where it supports research and exploratory development. Effective pursuit of the Department's goals should be the dominating consideration. Free competition among ideas and continued support of groups bringing valuable ideas to fruition should be encouraged to insure adaptiveness. Organization by tasks or projects, rather than by a stable organization tree, should be encouraged. Detailed definitions of scope and method of approach, schedules and organization plans, and other constraints which inhibit the free development of adaptive controls, should be avoided. Level funding of organizations, which removes the burden of many authoritarian controls, should be counter-balanced by orientation toward goals, competition based on evaluation of technical achievement, and other forces to assure that valid adaptive controls will arise to replace the authoritarian controls which are removed. Restrictive rules against the misuse of authoritarian power, such as those arising from civil service personnel policies, should be eased as authoritarian controls are lifted, in order to make it possible for adaptive controls to function successfully.

CONSENSUS-COLLABORATION AND COERCION-COMPROMISE RELATIONS

Regardless of organizational philosophies, the gross structure of most R&D laboratories and Defense Department agencies forces all intercourse between them into well-defined channels of control, authority, accountability, and communication. Discussions of how these channels work are simplified by introducing some more concepts and terms from behavioral science. The contrast between coercion-compromise and consensus-collaboration systems as described by Shepard (Section V-D, Table V-4) is related to the contrast between authoritarian and adaptive systems, and is especially easy to relate to such well-defined channels between two groups. The table shows nine interrelated pairs of contrasting characteristics. Most particular cases show many characteristics describing each particular relation.

In a typical consensus-collaboration system, the relationship is governed by mutual confidence and trust. Commitment to one another and to shared goals is rewarded, rather than obedience. The channel is used to pass information and ideas in both directions and to establish and review joint goals. Informal communication is possible because neither dispute nor censure is expected; it is required because there is no a priori basis to decide what must be communicated, and because attitudes and motives are as important in this system as facts. According to the circumstances, one or the other member may formulate a decision; implementation is based on consensus rather than authority.

In a typical coercion-compromise system, authority and power are unambiguously allocated. and the superordinate commands the obedience and controls the behavior of subordinates by using them. The subject matter of communication is circumscribed, and its content is expected to be defensible against challenge, for dispute followed by compromise is the normal way of resolving differences. Behavior obedient to the commands of authority is rewarded: "Theirs's not to make reply, Theirs's not to reason why, Theirs's but to do and die."

7. Consensus-Collaboration Relationship with Sponsors is Desirable

A consensus-collaboration relationship between the group doing the RXD and its sponsor was usually found (38/52). A number of nonexclusive factors were identified which support and encourage such a relationship. Those cited most frequently were:

- Long personal association between the parties (21/52).
- Attention of both parties focused primarily on the goals of the effort rather than the means (19/52).
- Strong technical insight on the part of both parties (14/52).

The distribution of these factors overlaps with no clearly significant correlations.

In most of the remaining Events (11/14) where there was a coercion-compromise relationship, a secondary informal communication channel was established which replaced or augmented the official channel of communications.

Knowledge of the need was communicated informally in most Events (46/52). Many of the scientists and engineers working on these Events had prior experience with military problems. The promoter of initial support for most (37/52) Events was closely associated with the conceivers of the Event, and the conceivers remained closely associated with the execution in nearly all (45/52) Events. In a large majority (42/52) someone closely associated with the conception or execution was also instrumental in bringing about utilization of the Event.

The Polaris Steering Task Group, made up of outstanding men from a number of agencies and firms with something to offer the Polaris system development, was cited many times as an instrument for rapid, uninhibited exchange of ideas and information, leading to decisions and action. Several of its members have told us that they would not participate in such a Group today, because interpretation of "conflict of interest" policies would now prevent their own firms from participating in the implementation of decisions arrived at in that way. Another inhibition which was remarked on is the restriction on communication between would-be purchasers and vendors during the period between issuing a request for proposal and the making of a competitive award. This prevents refinement of understanding of the job just at the period when all concerned are best motivated to improve it.

Recommendation

The Defense Department should simplify its administration of exploratory development in order to focus attention on the goals that motivate the effort, rather than the means of achieving them. Other factors, such as long personal association among the parties and strong technical insight, which are known to support consensus-collaboration relationships, should be encouraged. Emphasis on authority and obedience, sharp boundaries in scope of activity, separation of divers aspects of communication (e.g., technical and contractual) into different channels, and other factors known to lead toward coercion-compromise relationships should be discouraged by the Defense Department.

Open informal communications leading to cooperative formulation of goals and objectives and mutual understanding of needs and progress should be encouraged. The penalties for policies inhibiting open informal communications should be compared explicitly with their benefits. Where the Department is seeking creative, innovative work, it should eliminate policies which prohibit technical discussions between contracting organizations and would-be vendors, interpretations of "conflict of interest" which prevent well-informed and well-motivated men from advising the Defense Department and participating in development planning and conception, and other restrictions to free intercourse.

THE UTILIZATION OF EXPLORATORY DEVELOPMENT

Literature Findings

The test-tube stage of the technological process--the research laboratory--is the ideal time and place for scientific innovation and the free play of creative talents. Here competing ideas can grow and die in rapid succession and at relatively minor risk, and optimum variables and configurations can be selected.

This is not to say that we don't want innovation at an advanced engineering stage, or even in the manufacturing phase of an important project. We do, for innovation must traverse that route to the ultimate customer. But it is expensive to experiment at full scale, and the design of the new process, or material or method, is preferably done at small scale. A constant change in "final" design and performance objectives in response to the introduction of innovation, too late, causes the project completion date to recede constantly into the distance, and the expenditures to grow out of all relation to forecast costs.

This problem is met in its extreme case in the development of complex weapons and weapons systems in the Department of Defense. Because of the usually long development cycle, the typical horrible dilemma is the competition between the availability of hardware and its obsolescence rate. If the system design is frozen too early, it will be obsolete when produced, and if it is not frozen at some point in the development cycle, it will never be produced at all. The Solomon who sits in judgment in such cases must determine a certain point of no return, and at this point the innovators must be firmly ushered out of the room so that the production people can take over to manufacture, if necessary, a potentially obsolete product. Errors in judgment in this matter may be extremely costly, and in the specific case of weapons systems, could be fatal. To make the right decision here one requires, in addition to judgment, of course, a particularly clear, unblemished crystal ball, and a rabbit's foot of proven efficacy. (C.G. Suits)

We encourage the search for new inventions; we keep the mind stimulated, bright, and free to seek out fresh means of transport, communication, and energy; yet we remain, in part, appalled by the consequences of our ingenuity and, too frequently, try to find security through the shoring up of ancient and irrelevant conventions, the extension of purely physical safeguards, or the delivery of decisions we ourselves should make into the keeping of superior authority like the state. (Elting Morrison)

The cost of development is far greater than the cost of research, and if a big development gets off on the wrong foot, the price is terribly high. (F.R. Kappel)

8. Utilization of Research and Exploratory Development

Informal communication is as important in effective utilization of exploratory development as it is in the initiation. In most (33/52) Events, papers, patents, and reports were not important in bringing about the first utilization. The median delay between completion of an Event and its incorporation in a system development is around one year, but the spread is wide. The median Exploratory Development Event is initiated two years before the initiation of the development of the system in which it was used; but many (11/52) were initiated after system development. As noted before, most Events (33/52) derived some idea or stimulation from less basic development activity, e.g., advanced development, manufacture, etc.

A number of laboratory and weapons system contractor managment persons have expressed strong belief that some exploratory development funds should be made available during weapons systems developments. If such funds are not available, they contend that an environment is established in which they must choose between neglecting exploratory development which appears to be justified in order to improve the system, or risking proceeding with exploratory development under funding which is labelled by another category. In addition, if exploratory development advance funds are available, improvements can be made in the second generation of a weapons system, if they are achieved too late to be utilized in the first model.

Recommendation

The Defense Department should not rely only on papers and reports for the utilization of exploratory development. Informal personal communication should be encouraged. The cost of restrictive policies arising from security, competitive bidding, conflict of interest, mutually exclusive definitions of missions, etc., should be weighed against their benefits, and the Department should find ways to relax them where desirable for the good of exploratory development. Stimulation of exploratory work by system development, followed by prompt exploitation in the system, is doubly effective, and should be encouraged by free communication and by providing for the support and staffing of exploratory development in close association with operational system development and other nonexploratory activities.

COMPENSATION AND REWARDS

Literature Findings

A compensation plan must reward the research man as well as the corresponding skillful manager or the laboratory will soon be made up of many managers and few able researchers. Money may not be everything, but it is a long way ahead of whatever is in second place.(C.G. Suits)

Scientists and engineers, when they have solved a problem, should be rewarded, not necessarily with more money, but rather a distinct acknowledgement of their activities in arriving at the solution.(D.B. Keyes)

Engineers value most of all the feeling of service and accomplishment that goes with engineering work well done and the praise and acclaim of their fellow engineers, and the community at large.(W.T. Nichols)

Opportunity for individual growth both in salary and in other satisfactions is essential to a vital organization. A conviction on the part of employees that meritorious performance will be honestly appraised and adequately rewarded is a necessary ingredient of their loyalty.(R. Bown)

While pay, opportunity, technical challenge, security, and association with a good organization all affect the morale of scientists, two items stand out in their importance:

1. Confidence that the organization is well managed and is moving effectively toward realistic objectives.
2. Genuine feeling of being truly integrated into the business, of being an accepted, influential member of the business team. (R. W. Larson)

The spark of innovation frequently is the only absolutely indispensable element in a chain of events which produces technological progress. In view of this, however, it is distressing to find that the innovator's creative contribution may be lost sight of in the vast welter of subsequent activity that takes place under the heading of reduction to practice. (C.G. Suits)

9. Compensation and Rewards

In view of the existence of the report to the President on Government Contracting for Research and Development (30 April 1962), which dealt at length with compensation structures inside and outside of the Government, we decided to take a different approach to the subject of salary.

In our interviews, questions were asked about a wide range of environment details; but rather than discussing salary directly, we dealt with such matters as group morale and motivation, and waited to see if the subject of salary would be mentioned. Surprisingly, it never was. We can only conclude that men working on successful exploratory development projects, within the environment of a well-managed laboratory (and most of our cases were), have a feeling that their efforts are being recognized and that management is treating them fairly.

However, we did encounter a distinct feeling on the part of the innovators that their successes had gone unrewarded. In many cases, we were among the first people from outside the laboratory to call upon the scientists and engineers concerned to discuss their successful exploratory development Event. Needless to say, we were almost invariably provided a warm and enthusiastic reception.

Recommendation

While compensation is certainly a most important factor in environment, the Department of Defense can and should take steps, as noted in various recommendations in this report, to improve other environment factors to assist in offsetting compensation differences where they exist.

In particular, the Department of Defense should recognize in some appropriate ways those scientists and engineers who have contributed developments utilized in operational weapons systems.

C. FINDINGS AND RECOMMENDATIONS CONCERNING RESEARCH ENVIRONMENT

The work under this assignment uncovered only 11 Events which fit the definition of Research stated by the Department of Defense:

> Research (6.1) - Includes all effort directed toward increased knowledge of natural phenomena and environment and efforts directed toward the solution of problems in the physical, behavioral and social sciences that have no clear military application. It would thus, by definition, include all basic research and in addition, that applied research directed toward the expansion of knowledge in various scientific areas. It does not include efforts directed to prove the feasibility of solutions of problems of immediate military importance or time-oriented investigations and developments. The research elements are further characterized by using level of effort as the principal program control.

This number of events is obviously insufficient to permit any detailed study of research environment as distinct from exploratory development environment. Nevertheless, it is important to comment to the extent possible on this subject.

In the United States, approximately one half of the funds designated as research expenditures flow to work performed in colleges and universities, with the remaining half being distributed between industry, government and non-profit institution laboratories in that order.

It is thus clear that the traditional environment for research springs from the universities. The trend has been for nonuniversity laboratories performing such research to emulate within their research sections a university-type environment. Extensive literature exists on this subject. We propose to base our limited observations in part upon this literature.

THE CASE FOR RESEARCH

Literature Findings

Why should the Department of Defense support basic research rather than leaving it entirely to other government and nongovernment agencies? The answer is at least threefold.

The Department of Defense requires the most advanced technology much more than civilian industry does. Its technical problems are greater than those posed by the civilian technology. It always operates in its development program at the limit of known science. The Department of Defense cannot therefore entrust the responsibility for scientific progress entirely to other agencies which are not aware of its desperate necessities.

Secondly, the Department of Defense must see to it that the United States is in the very forefront of science in order to protect its vast investment and the security of the United States against technological surprise and to avoid obsolescence. The whole defense system of a country can be outflanked by a new scientific advance such as atomic weapons or radar when this equipment is not a part of its arsenal.

Thirdly, the Department of Defense must support basic research in order that its body of officers and civilians are kept continually aware of scientific advance. It can remain in close contact as a part of a routine through awarding of contracts, justification of budgets and programs, etc. Liaison officers alone cannot do the job because they would lose the intimate connection with the scientific community. (I.I. Rabi)

Certainly no one can take issue with the necessity for basic research, for to do so would be to deny the impact of human creativity on our spiritual and material well-being. Each step forward in man's progress can be traced back to a flash of creative genius in the mind of some gifted individual. To him the utility of his brainchild is far less important than his success in penetrating to some small degree the dark curtains of our ignorance. The financial support of academic research, it seems to me, is a clear responsibility of industry and government. (Crawford H. Greenewalt)

The security of the United States depends today, as never before, upon the rapid extension of scientific knowledge. So important, in fact, has this extension become to our country that it may reasonably be said to be a major factor in national survival (Scientific Research Board Report to the President 1947)

There is nothing which can better deserve patronage than the promotion of science (George Washington)

1. The Case for Research

The fact that this study disclosed only eleven research Events (all connected with the work on transistors at the Bell Laboratories, and the work on gas dynamics at Cornell and Avco) should not be misinterpreted to mean that research is not of vital importance to the Department of Defense. While the ultimate importance of just these few Events to weapons systems can hardly be overestimated, it is not a central purpose of this report to make a case for the role of research. The case for research has been stated eloquently in the facing quotations, and in detail in various publications.*

The indication that this study did bring out was that the technological understanding on which the exploratory development Events were based had, in general, been available about five years prior to the initiation of the exploratory development Event. Furthermore, in a predominant number of cases the Department of Defense was supporting research in the particular fields of science in which the advances were made. Thus the investment strategy of the Department of Defense in research was, in most cases, assisting in developing knowledge in those technologies necessary to the evolution of future operational weapons systems. The only investment strategy we could uncover was the classical one of backing persons of known capability in the field of science of interest (10/11).

*Basic Research in the Navy, June 1, 1959; Symposium on Basic Research, May 1959.

THE ATMOSPHERE FOR RESEARCH

Literature Findings

The main requirement in support of basic research is to pick a man of good quality rather than being too particular about just what he does in fulfilling the terms of the contract. (W. F. Libby)

There is no better way to "tone up" a research staff and its over-all program than to encourage--insist upon if need be--some fundamental research. (Roger Williams)

The interaction of research workers with development engineers in industrial laboratories is important to development--both in direct consultation and in longer-term continuing education--and such communication can be important to the research man too. His role in this interaction is to "keep the thinking straight," to reduce empiricism, and by physical insight and analysis to infuse development activity with scientific method. The quality and tone of a development organization are importantly influenced by the presence of a good basic research activity in the industrial laboratory. Research personnel can also be a source of excellent development engineers at a proper stage in a man's career, as experience has shown. (J. B. Fisk)

In the government and in the universities the strategy of research continuing right through to development and engineering technology is too often enslaved by a misconceived devotion to cause and effect. The freewheeling individual researcher knows that he cannot trace in advance step by step the measures necessary to invade a problem. It is a foolish conceit for an industrial laboratory or a government program, and, particularly, in military affairs for a technical fallacy known as a set of requirements, to believe that step-by-step charting of a course into the unknown can be done. (W. O. Baker)

We all believe that the real key to basic research is the continued stable support of the individual research man, to give him full freedom, with moderate austerity, to investigate problems in which he is interested. (Merle A. Tuve)

Those scientists having the ablest and most creative minds will prefer to use them in basic research by following up the undirected, uncontrolled, unspecified, unprogrammed and certainly unknown courses revealed as the work goes ahead. (W. O. Baker)

The basic researcher, needs to be protected from the pressures and concerns which typically permeate the going enterprise. His attention must be directed outside the enterprise into the ecology, and there to a set of peers who work in approximately the same field of abstraction and speak the same language, who will evaluate and stimulate his work on criteria grounded in theory. The applied researcher, on the other hand, needs to be fully exposed to the usual pressures of product cost, sales appeal, production schedules, etc. He must, therefore, be well integrated in the larger enterprise and in frequent iteration with those who will produce, use and distribute his products. (George P. Bush and Lowell H. Hattery)

2. Atmosphere for Research

The literature on research environment emphasizes the need to select good men, provide them with the facilities and equipment they require, and then give them freedom to pursue problems of their choice, freedom to communicate with others in related fields and freedom to publish.

It is clear that the Military Departments must strive to invest the majority of their research funds in fields of science which are related to their missions. Some funds must also be invested in fields less obviously mission-related because of the unpredictability of research results and the complex interrelationships between fields of science. In a number of our interviews it was apparent that the science administrators of the Departments, working with the advice of outstanding scientists, have developed competence in this area, particularly in the Office of Naval Research.

In all the 11 cases we studied, the environment fitted the classical university pattern. The workers were given freedom to the point that generalized work statements were used and the paths of investigation not questioned. Thus the environment was approaching one of permissiveness. It would seem that the Department of Defense should support this policy as strongly as possible. Any attempt to place controls in their area will simply cause the scientists to seek support elsewhere as they will insist upon their traditional environment of freedom.

In 10 of the 11 cases the research Event was performed in laboratories which also carried out development work.

Recommendation

In view of the fact that research is of vital importance in providing the knowledge and understanding from which technological advances spring, it is recommended that further data be gathered in subsequent studies to cast more light on ways and means for the Department of Defense to promote favorable environments for research within its own laboratories as well as in those with which it contracts.

D. COMMENTS WITH RESPECT TO FURTHER STUDIES OF RESEARCH AND EXPLORATORY DEVELOPMENT MANAGEMENT

It is believed that this study, while preliminary in nature, has served the purpose of indicating that information of importance to the Defense Department regarding research management can be derived from a study of the history of the research and exploratory development aspects of operational weapons systems.

The obvious weaknesses of this preliminary study are the narrowness of the data base, and the fact that the environments of "failures" or unutilized Events were not studied.

Four important lessons were learned during the course of this study which should be taken into consideration when establishing the methodology to be utilized in future studies:

- Less time should be spent on the RXD Event Descriptions and correspondingly more time devoted to environment studies.
- More social scientists should participate in order to add to the depth and understanding of environment information.
- More attention should be devoted to those portions of the Department of Defense involved in research and exploratory development management which must interact with the Government, university and industry laboratories.
- The scope of weapons systems histories should be augmented to include more information about research and exploratory development.

Recommendation

The Department of Defense should extend studies of this type into additional weapons systems in order to broaden its knowledge and increase its effectiveness of the management of research and exploratory development. Greater participation by in-house personnel in such studies would provide valuable training. However, it might prove to be necessary to use some outside assistance in order to obtain objective information, particularly in the sensitive areas of "failures" and of relationships between outside contractors and the Department.

II. DISCUSSION OF DATA, FINDINGS AND RECOMMENDATIONS

A. INTRODUCTION

The following section shows how data about the environments of RXD Events support the conclusions and recommendations already disclosed in Section I. The environments of a total of 63 RXD Events were studied, of which 11 represent Research and 52 represent Exploratory Development.

Not all of the RXD Event Descriptions tabulated in Appendix C are included in the detailed study of environments. First, only those we believe to be research or exploratory development are considered. When a final evaluation was made, a number of the Events in Appendix C were ultimately judged to be more characteristic of Advanced Development. Secondly, any Event in which the bulk of activity took place before 1946 was excluded, because their number was small, the period of WW II was atypical, and the effort required to gather a complete environment description was large. Finally, a small number of Events included in the library of RXD Event Descriptions were excluded from the environment study, either because their environments overlapped substantially or because their descriptions were incomplete and the amount of effort required to complete them seemed excessive.

Because of the way in which these RXD Events were identified, we have no reason to believe they represent a random sample. We can anticipate that our methodology favors recent Events and Events closely associated with the particular weapon system development activities studied.

The observations in the next section are based on the totality of evidence at our disposal, including RXD Event descriptions, trip reports, responses to the Standard Environment Questions in Appendix D, and the recollections of staff members. In order to sharpen the distinctions, a number of very specific questions were posed as various hypotheses were formulated (questions described in Appendix E). These questions were answered by the staff member who conducted the field interviews, but without referring back to their sources. A machine computer print-out of the responses and a tabulation of their frequency distribution are also presented in Appendix E. Exploratory Development Events are separated from Research Events, but otherwise the identification of particular Events is withheld, and their order scrambled to protect the confidence of our sources. Each horizontal line in the print-out refers to a single Event among those listed in Appendix C.

B. INITIATION OF RESEARCH AND EXPLORATORY DEVELOPMENT

1. Strategy

When this study was begun many people believed that weapon system development depended on a succession of "key Events" and important technical and scientific breakthroughs. The evidence gathered from the six historical surveys undertaken in this study show that this is probably not true. Most of the RXD Events which have been discovered result in modest innovations, which however make an important contribution to the value of the weapon systems in which they are used. In every case, the weapon system affected is significantly better than its predecessors in performance, operational utility, or cost.

In most cases, the performance improvement cannot be attributed to one innovation only, because its value will depend on the exploitation of other innovations at the same time. For instance, the high search rate of the Mark 46 torpedo guidance system is only useful because of the high speed of the vehicle. This is possible only because of several innovations in the fuel and motor. These in turn put requirements on the propellor, on hydrodynamic noise reduction, and on signal processing, which utilize other innovations. The result is a vastly improved torpedo, but the RXD Events taken individually are not major technical breakthroughs or key ideas.

We have screened several hundred ideas and innovations in the background of six weapon systems. The search favored the discovery of large, spectacular advances, for the methodology depends mostly on what people remember. Over one hundred discrete innovative efforts have been identified, and most have been written up as RXD Events. Only two of these, the invention of the transistor and the development of a high-temperature shock-tube, could be considered a key idea or a major technical breakthrough. (Another major breakthrough, the nuclear warhead, was in a technical area we avoided because of secrecy.) The estimated cost of these two RXD Events is less than a million dollars, and the total cost of all the RXD Events we have studied is over $20 million. We infer that the major expenditure in research and exploratory development is not for key Events and important breakthroughs, but for a very much larger number of significant but individually small innovations.

Even though the verdict of history makes most RXD Events look small, each was a contribution of substantial importance in its own era. We have attempted a rather coarse and subjective evaluation of the degree of speculation which would have been perceived by a reasonably competent observer, prior to this Event, confronted with the decision to invest money and resources

in an effort to accomplish the Event. In 57 Events (8R, 49XD) the initial probability of success coupled with the potential value of success to weapons technology overwhelmingly justified the Commission of resources. Though the finding is biased by the fact that only successes have been studied, the implication is that the initiation of utilizable research and exploratory development most often has not involved controversial investment decisions.

Even after the passage of years, a clear DOD investment strategy appeared in the background of 33 Exploratory Development Events. The strategies can be catalogued in seven broad nonexclusive classes. Most of these are well-recognized in university and industrial research, as well as in military and other branches of government sponsored research. Others may be more peculiar to weapons development. These classes and their frequency of occurrence are as follows:

a. Invest in fields of research and development characterized by--

obvious continuing interest in weapons technology, and/or

a rapid rate of change in the state of scientific understanding and technological exploitation, and/or

a clear current need for improvements. (17 Events)

b. Invest in research and development institutions characterized by--

a record of accomplishment, and/or

facilities well matched to the work to be done, and/or

access to university resources, and/or

an objective approach to alternate solutions, and/or

a director whose dynamism inspires confidence. (5 Events)

c. Invest in men of distinguished accomplishment in the field of interest. (3 Events)

d. When the need is clear, support evaluation work on all ideas which show even remote promise of meeting the need. (5 Events)

e. Allocate some discretionary funds to a large class of research and development institutions, recognizing that creative ideas occur at random, that broad awareness of military needs will promote productivity, and that the capacity to evaluate randomly occurring ideas promptly is desirable. (2 Events)

f. Force technological progress by attempting to develop a weapon system even though advances in a number of areas will be essential to success. (4 Events)

g. Focus research and development effort by clear statements of weapon system performance requirements, but let technological advances pace system development effort. (3 Events)

Because of the size of the sample, the relative frequencies of these strategies are not significant.

Our observations do not support the view that research and exploratory development are phases in an orderly progression from basic research through exploratory development, advanced development, engineering development and system development to production and use. In fact, in 40 Events (10R, 30XD), the changes in the character of activity which correspond to the transition from research to exploratory development or from exploratory development to advanced development were not clear. Furthermore, in 41 Events (8R, 33XD), the activity derived some essential idea or stimulus, or information, from a less basic development activity; that is, an RXD Event characterized as exploratory development derived some idea, stimulus, or information from some advanced development, engineering development, operation system development, operation, test or evaluation. Eleven Exploratory Development Events started after the initiation of system development in the system in which the Event was used, and derived various kinds of stimulation, including financial support, from the system development. A significant proportion of worthwhile exploratory activity has been carried on where exploratory development overlaps advanced development and system development, and the circumstances are such that we believe the exploratory development activity benefits from the intimate contact.

To summarize: most advances from RXD result from innovations whose value is moderate but clearly larger than the expected cost of the RXD. The required investment decisions are not controversial. A superficial review of strategies reveals that a number have been used, but none is obviously dominant.

Based on these general findings, we recommend that the Department of Defense show substantial concern for small innovations, and not be preoccupied with major breakthroughs. The jet engine, the magnetron, the

transistor, and nuclear fission are important, but they are not the only kind of advances which our progress depends on, and they probably account for only a small proportion of our research and exploratory development expenditures. The Department should continue to improve strategies of RXD investment. Most of the technical decisions are not very controversial, and could (later sections suggest they should) be delegated to men quite close to the exploratory work, such as laboratory directors, project managers, and experienced RXD personnel. The kinds of work described as research, exploratory development, advanced development and so forth, should not be forced into mutually exclusive classes, nor should exploratory effort be divorced from operation, manufacture, and system development unless some benefit accrues which compensates for the penalty to the exploratory efforts.

2. Initial Triggering of an RXD Event

In 49 Exploratory Development Events and ten Research Events, the burst of successfully utilized exploratory activity which we have called the Event started only when the three following elements were present:

a. An explicitly understood need, goal, or mission;

b. A source of ideas, typically a pool of information, experience and insight in the minds of people who could apply it; and

c. Resources, usually facilities, materials, money, and trained and experienced men, which could be committed to do a job.

As an illustration, consider RXD Event No. 20, the Development of techniques for the preparation of sound thick sections of highly oriented pyrolytic graphite (Appendix B). This activity was carried out in the Materials Section of a nuclear power group in the Research Division of the Raytheon Company. The nuclear power group was working on a concept for a liquid-metal fueled, gas-cooled nuclear reactor.

The particular need in this case was for a suitable impermeable protective coating for graphite, to permit its use as a primary material of construction. The properties of graphite make it particularly suitable to serve certain functions in a reactor; impermeability was desired to control the diffusion of the gas coolant. This particular formulation of the need was jointly arrived at by the people in the Materials Section and other scientists and technologists actively engaged in reactor design. The over-all goal, which was shared by the Materials Section, was to demonstrate the superiority of a nuclear reactor based on some novel concepts.

The resources were the Materials Section itself, with its staff and facilities, organized and established quite explicitly to do work of this character as part of a general program to develop a new reactor.

The source of the ideas was the members of the Materials Section. Most of them were young and had considerable academic background and some professional experience, although they had not had any opportunity to build broad professional reputations. Many of the members of the group had come from the Canel Project at the United Aircraft Company, and therefore had significant experience in reactor problems and in the development of materials for use in reactors. They had further opportunities to explore this area of professional activity after the Materials Section was formed at Raytheon in the Nuclear Reactor Division.

Nearly all of the RXD Events show this same general pattern, but there were three exploratory development Events which were exceptions. In each, understanding of a need was lacking; instead, these Events were a rapid, flash-of-insight inventions. In the one Research Event which was an exception, the lead investigator appeared to be well motivated, but not by an external mission or goal. His motivations were closer to the scholarly ideal of broadening his understanding and of fulfilling his scholarly responsibility by generating new knowledge and passing it on to the world.

The three elements listed above can come together in various ways, and various time sequences. We can regard the last element of the three as the "trigger" which initiates the Event. In 18 Events, (2R, 16XD), this trigger was the allocation of resources to look for ideas in order to meet a recognized need; in 28 Events (6R, 22XD), the trigger was the occurrence of an idea or invention with clear potential to meet recognized needs using available resources; and in 17 Events, (3R, 14XD) the trigger was the recognition that a need existed which could be met by an idea and resources already at hand.

The traditional method of stimulating technological advance is to recognize or anticipate a need, and then allocate resources for exploratory work in search of ideas to fill that need. These findings reveal two alternatives. The first, stimulating or recognizing ideas and inventions, probably cannot be achieved by a deliberate plan; however, it is possible to provide environments which foster creative inspiration. (Such a course presents special problems to the Department of Defense, but casual observations elsewhere during the course of this study make us believe that the Department of Defense has missed opportunities to follow this plan where it might be useful.) The second alternative plan is to formulate and promulgate needs so that they are understood wherever ideas may spring up in the presence of resources to exploit them. More is said about this alternative in a later section.

The triggering element generally occurred from one to two years (median) after the other two elements had been joined, but the distribution of delay time was very broad. For half of the Events the technological base had existed five or more years prior to Event initiation: that is, except for the particular innovative idea which formed the kernel of the Event, all the other science and technology involved had existed and been available for five or more years. Again, the distribution of times is very broad about this median. This clearly suggests that more rapid technological advance is possible if there could be a more rapid bringing together of needs, idea sources, and allocable resources in the right kind of environment.

In 57 Events, (10R, 47XD), the initial activity occurred at the place where the idea was generated, no matter which among the three elements above was the trigger. In a later section it will be shown that the atmosphere conducive to executing research and exploratory development is also one likely to encourage original ideas, and one likely to have resources available.

In 32 Events, (5R, 27XD), a recognition of a specific need followed some time after a more general need had been widely recognized. In 30 of these (5R, 25XD), the Event was responsive to the more specific need rather than the more general. For example, RXD Event No. 86, the design and demonstration of a low-cavitation propellor, was based on general work started at Naval Ordnance Research Laboratory at Pennsylvania State University. This work primarily took the form of theoretical analysis and experimental studies of hydrodynamics at the Garfield Thomas Water Tunnel, and it was carried on for six years in the absence of specific requirements for high-speed quiet propellors.

In 1954, the Bureau of Ordnance made a specific request concerning the feasibility of a high-speed, low-cavitation propellor for use in torpedoes. With this stimulus, an experimental propellor was designed and demonstrated in about a year. We are told that ORL had claimed for about five years before that they could design such a propellor, but no actual design appears to have been undertaken until the specific need was pressed. Since then, the design of high-speed, low-cavitation propellors has become commonplace.

Logically, making a need more specific reduces the range of acceptable solutions. Nevertheless, in this case and in most of the others, the work which actually achieved a utilized result was stimulated by the specific need. Furthermore, this work resulted not only in a specific propellor, but in general design methods so broad that no further work on this class of propellors is likely to be called exploratory development.

The recognition that solution of a special case often leads to the intellectual insight required to understand a general problem has been made, for example, by George Polya.[1] It may contribute also to motivation and commitment, which are shown in later sections to be significant.

The prevailing pattern for the initiation of an RXD Event is the following: a need, a source of ideas, and resources are brought together in some sequence; upon the commitment of resources, work begins, usually where the idea was generated. An RXD Event can be initiated by broadcasting an understanding of needs, particularly of a specific need, or by prompt nourishment of ideas which spring up where they were not anticipated, as well as by the more systematic and traditional plan of systematically allocating resources. The Defense Department should try to take advantage of the alternate ways of stimulating exploratory activities. Also, the Department should note that most innovative ideas which come to fruition are nourished initially where they are generated, and should avoid policies which result in transferring RXD ideas from one place to another before they are well formed.

3. Initial Funding

In 53 Events, (10R, 43XD), work was started promptly after the need and the idea were brought together. The standard is the subjective standard of our respondents. Their remarks, stimulated by questions, reveal whether the participants felt any delays or whether the activity was simply based on the time it takes to do the work. In ten cases there was a delay between getting the idea and commencing work. The delay was nearly always to get money, usually a supporting contract.

Logically, it might seem that an expression of need and an idea for fulfilling it would together make up something valuable. One could well imagine storing such combinations and reactivating them according to some scheme or priority when it becomes feasible to start work. However, none of our examples exhibit this pattern. The closest example we have appears to be RXD Event No. 13, conception and demonstration of thrust reversal in a solid propellant rocket motor. Here the conception occurred in 1951, and was written up in a report in June, 1952, by H.S. Seifert at the Jet Propulsion Laboratory; because his own laboratory administration was unwilling to support experimental work, the idea lay fallow. The decision was not motivated by a shortage of funds, but by the judgment that the idea was not as good as others competing for attention. In 1955, Ritchey at the Thiokol Chemical Corporation, Redstone Division, initiated an experimental investigation of thrust termination methods. One of the two methods studied was the thrust reversal technique advocated by Seifert.

In contrast to this, we have many examples where an idea was forgotten and then rediscovered. RXD Event No. 16 is an example. This work, on canted rotatable nozzles, was carried out in good faith, and was actually used in the Polaris system in the form developed by Kershner and his associates at the Applied Physics Laboratory of Johns Hopkins University. However, when a patent application was filed for the idea, it transpired that a similar idea had been filed on previously. Apparently the first statement of the idea was not readily available to Polaris, and was lost as far as application to Polaris was concerned.

The systematic review by the Patent Department is intended to reveal interference and to identify the inventor having priority. Since our methodology has not provided for any systematic study of priority, we cannot make a valid estimate of the number of times an idea is discovered, lost, and then rediscovered and acted upon. Other studies, including one carried out by Arthur D. Little for the National Inventors' Council,(2) show that if an idea is set aside on paper, for consideration by someone else at a later time, it is not likely to result in the undertaking of a technical research or exploratory development program.

It is interesting to note that under the traditions, precedents and statutes of patent law, an invention is not considered complete until it is diligently reduced to practice. Lack of diligence--that is, failure of the inventor to work steadily and continuously from the time of his conception until he reduces the invention to practice or files a patent application--limits the rights which he may claim to his invention.

The pattern of initial funding is shown in the following table (Table II-1) Forty-three Events (8R, 35XD) were launched with funds and resources specifically allocated for discretionary expenditure, or already allocated for the support of related work whose description fitted the work comprising the RXD Event, but in which the particular RXD Event was not specified or anticipated. In an additional 7 (1R, 6XD), it was acknowledged that funds or resources were borrowed from other activities. In only 13 Events (2R, 11XD) was the activity supported by funds specifically set aside for this activity or specifically approved after the idea was brought forth.

It is interesting to note that in four of the five cases where work was done on funds specifically approved by the Department of Defense for the RXD Event after the idea was generated, it was reported that resources were not instantly allocated. Delays ranging from six to 12 months were reported. On the other hand, no delay was reported in the three instances where private funds were specifically approved for work after the idea was generated. It appears that funds for the private support of research and exploratory development may be allocated so quickly that the formal approval process is not felt as a delay.

TABLE II-1

PATTERNS OF FUNDING

	Source					
	DOD			Private		
	R	XD	Total	R	XD	Total
1. Available for discretionary expenditure	0	4	4	0	3	3
2. For the support of related work, but in which the particular RXD Event was not specified or anticipated	2	21	23	6	7	13
3. Borrowed from other activities	0	6	6	1	0	1
4. Specifically set aside for this activity (possibly as one of many) before initiation	0	3	3	0	2	2
5. Specifically approved for this work after the idea was generated	1	4	5	1	2	3

A dominant funding pattern emerges when the first three classes are taken together. In 50 Events (9R, 41XD), the initial funding of the RXD Event did not involve a formal defense of the merit of the activity before it was commenced. Implicitly, or explicitly, the responsibility for deciding that the work merited support was passed on to those who were about to do it and to their immediate associates; failure to allocate resources promptly certainly has caused some ideas to be lost, and evidence in a later section will show that it may discourage people from generating ideas. The common pattern for initial funding is for resources or money to be committed promptly on the basis of a local decision. Thus, it would seem that the Defense Department should make further provisions for prompt commitment of resources for initial exploratory efforts, and should make sure that the real initiative for making such allocations is local. They should not require controls which involve justification based on the promise of particular ideas or methods of approach in anticipation of work. Further, their controls should not introduce delay, and should operate so that the real decision to proceed is made locally. Some suitable kinds of controls are discussed in a later section.

C. EXECUTION OF RESEARCH AND EXPLORATORY DEVELOPMENT

1. RXD Flourishes in an Adaptively Organized Group

In 62 Events, (11R, 51XD), the local environment was adaptive rather than authoritarian. (The words adaptive and authoritarian are used here in a particular sense. Their outstanding characteristics are shown in Tables V-2 and V-3, and explained later in Section V-D.)

In a typical authoritarian environment, authority is based on position in a hierarchy. Goals are well-defined and specific, and change slowly and infrequently. Tasks are broken into component parts, and are delegated by authority at the top of the hierarchy, together with nonoverlapping authority and responsibilities necessary to execute them. Various parts of the organization can function independently. Chains of command, channels of communication, responsibility and authority, and content of tasks are well defined for each position in the organization, in such a way that they are mutually compatible.

By contrast, in a typical adaptive environment, authority is based not on position in the hierarchy but on expertise with respect to the task at hand. This means that critical decision making is not confined to the top of the pyramid but is diffused throughout the organization according to each man's ability to contribute wisdom where he has knowledge, experience, or talent. Control in an adaptive organization is achieved by having as many individuals as possible refer their decisions and actions to goals and standards. This means, of course, that goals must be very well understood throughout the organization, and standards must be sufficiently shared that decisions made by one will be endorsed by the others. Communication is not through channels, since who is at the "top" of the decision-making hierarchy depends on the content of the decision. Values and motives must be communicated as well as technical facts, for there is no prescribed channel of authority with a recognized power to give rewards or invoke sanctions.

The various characteristics in which these idealized types of organization systems differ are strongly correlated: a small group has either most of the qualities of an authoritarian system or most of the qualities of an adaptive system, but rarely a half and half mixture. When we looked both at the general question of whether the local organizational system was authoritarian or adaptive, and at a number of specific factors which are expected in adaptive environments, we discovered that the environments in which these RXD Events were carried out are nearly all adaptive, according to either standard.

The way we examined the environment of Event No. 93, the Development of the H-6 High Explosive, illustrates the process we used when first developing experience. During our visits at the Naval Ordnance Laboratory, we accumulated about 30,000 words of trip reports and interview transcripts. These were sifted for statements or groups of statements matching the descriptions given in Tables V-2 and V-3. No attempt was made to weight the statements, but a consecutive sequence of statements from one interviewee was counted as a single statement. The results were as follows: Fourteen statements described characteristics typical of an adaptive environment: Five more drew contrasts showing a characteristic of adaptive environments present in 1950-52 which has been replaced since by the related authoritarian characteristic. These 19 statements tend to characterize the environment of Event 93 as adaptive. Similar reckoning revealed only five which characterized it as an authoritarian environment, and the 19-5 imbalance is further accentuated by the fact that three of the five had to do with the personnel relations of one man said by his colleagues to be a misfit, who moved out of the research laboratory very shortly thereafter into an administrative position in an institution which does not carry on research and development.

After looking at a few examples, we have found it unnecessary to go to the trouble of a numerical tabulation of particulars. In most instances, the most casual review of the remarks made by our respondents clearly established the environment as belonging to one or the other type in its dominant features. With this understanding, we found the local environments of all R and all but one XD Event to be adaptive.

We attempted to account for the degree of adaptiveness by searching for the presence of factors encouraging adaptivity. Those which we observed most frequently are listed below, in decreasing order of incidence.

a philosophic commitment to adaptiveness on the part of the laboratory management (11R, 23XD)

laboratory organization by tasks or projects (0R, 22XD)

a rapid growth in the size of the organization, which enhanced fluidity (2R, 13XD)

a dominant adaptive personality (3R, 11XD)

the influence of goals whose importance transcended other considerations (3R, 11XD)

a competitive drive which transcended other considerations (0R, 11XD)

Although the transcendent competitive drive was reported only in 11 XD Events, the desire to show the superiority of a technical approach or capability over conventional approaches or those being worked on elsewhere was reported in 45 Events (10R, 35XD), as a positive contribution to success or effectiveness. In only 3 XD Events was such competition reported as producing an adverse effect. Where competition contributed to success, it was usually by focusing attention on true goals and by providing an additional goal-oriented motivation. Competition is not commonly cited as a characteristic part of adaptive organizational controls within an organization, but competition from outside served to reinforce an adaptive system, by providing values and motives common to everyone in the organization which could be talked about freely.

The frequent statement that research and exploratory development must be directed permissively, with looseness, relaxation of restraints, and so forth, is incomplete. The constraints arising from an adaptive system are fully appropriate; total lack of direction is not associated with successfully utilized research and exploratory development.

Complete permissivity can be regarded as an ultimate and extreme case of the operation of an adaptive system, where one person is so much more capable and so much better informed than his associates and sponsors that his judgments and decisions are endorsed by the group without any intercommunication, review, or other consideration. This may be the case where one man is working alone in an area where he is well qualified, or where an experienced and able man is doing basic research under circumstances where his understanding of the problem is far ahead of that of his contemporaries.

People who are accustomed to working with an authoritarian system often recognize that its ordinary methods of control are inappropriate, but cannot formulate a description of the appropriate substitute. It is likely that they cannot perceive any control or, for that matter, any organization at all, in a fully adaptive system, which they would characterize as loose, permissive and lacking control; they may complain with great vigor about the inefficiency of an adaptive organization and declare that it is chaotic, "screwed up," poorly managed and otherwise unfit to be given serious consideration.

However, we find evidence that adaptive controls were actually invoked in all 11R and in 49 XD Events. Absolute permissivity existed in only one XD Event; in two, our information was incomplete or equivocal.

The local environment with which we concerned ourselves is that comprising the individuals who did the research and exploratory development and those with whom they had first-hand contact. This group would be part of a considerably larger formal organization, such as a formal special project

group, a research laboratory attached to a manufacturing organization, or a government laboratory operated by one of the services. In all 11 Research and in 44 Exploratory Development Events, the larger organization was predominately adaptive. The remaining Exploratory Development Events include one in which authoritarian controls were frustrated or overthrown but no clear adaptive pattern emerged, and five in which the group functioned adaptively despite an authoritarian formalorganization (part of their adaptivity must have been devoted to insulating themselves from the authoritarian environment).

There is evidence in 11R and 47XD Events that personal enthusiasm, dedication, and commitment to the achievement of goals was present and that it contributed to success or effectiveness. To dignify such a trite statement as a finding of a research study appears fatuous, but it has a real point. Compare this statement, stemming from field observations from 63 examples, with the assumptions about human nature and human behavior comprising Douglas McGregor's "Theory X"(3) (Section V-D, Table V-5):

> The average human being has an inherent dislike of work and will avoid it if he can.
>
> Because of this human characteristic of dislike of work, most people must be coerced, controlled, directed, threatened with punishment to get them to put forth adequate effort toward the achievement of organization objectives.
>
> The average human being prefers to be directed, wishes to avoid responsibility, has relatively little ambition, wants security above all.

McGregor believes that these assumptions underlie the traditional view of direction and control, the one which we find exemplified by authoritarian systems of management. Our datum indicates that any system of management founded on McGregor's Theory X assumptions is probably inappropriate. On the other side, McGregor's "Theory Y" assumptions include:

> Man will exercise self-direction and self-control in the service of objectives to which he is committed.

Our datum indicates that a system of organization based on Theory Y assumptions is, in this respect, consistent with the way in which we have observed successfully utilized RXD has been done in the past. Insofar as adaptive organizations are based on Theory Y assumptions about human behavior, and authoritarian on Theory X, our finding that the environments in which these RXD Events were done were adaptive is further supported.

The exercise of local discretion in undertaking work and committing funds and resources was mentioned in Section II B 3 as part of the common pattern for initiating an RXD Event. In an adaptive organization, local decision-making is routine; this is further evidence that adaptive organization favors the initiation of an RXD Event. As observed in II B 2, most RXD Events are executed where the important initial idea was generated; this suggests further that an adaptive environment may favor the generation of new ideas in response to stimuli such as needs.

Getting an idea, initiating an RXD Event, and executing an RXD Event are so closely allied that we could not tell whether adaptive organization supports one more than the others. Sociological theory suggests that it should be helpful in executing RXD, important in initiating it, and essential in eliciting new ideas.

A number of recommendations can be based on this observation that research and exploratory development flourishes best in an adaptive environment. In the first place, an adaptive environment is easy to recognize, and its presence could be used as part of a selection procedure in choosing research and exploratory development sources. This will cause no disturbance in the research and development community, for this kind of management pattern is widely recognized as desirable, and is found at the working level of nearly every successful R&D organization. Secondly, the Defense Department should take advantage of the qualities of existing adaptively organized groups, particularly in searching for new ideas. To do this, they must shed some of the constraints of formal communications normal to an authoritarian organization. Third, the Department should encourage and support adaptive organizational behavior in their R&D suppliers. For an adaptive organization to function, it must have material support and it must have access to information about real needs, goals, missions, and the values by which efforts are judged. Encouragement can be given by rewarding truly valuable action and by recognizing and applauding original, creative, imaginative, novel, change-producing behavior. Fourth, the Department should avoid inhibiting adaptive behavior. Many common ways of defining tasks and describing jobs are in the authoritarian tradition of limiting scope and compartmentalizing authority. Many work descriptions describe a method of approach of the organization of a team, rather than the goal to be achieved. The wording of many RFQ's encourages a response with an organization plan showing separation of functions, subdivision of responsibilities, and localization of authority. These and controls on accounting, conflict of interest, security and other procedures limit the free exercise of adaptive organizational control. The Department should avoid routinely adopting the standard of the easiest alternative, and should bear in mind that the advantages to be derived from a successfully operating adaptive group may offset the penalties of procedures which in other contexts are not the most desirable.

There are three particular recommendations which it is probably easier for the Defense Department to use than the others: first, direct attention to real needs. Second, evaluate results according to their true value in a general scheme of values, rather than by the adherence to agreements. Competition may help to achieve this. Third, avoid burdening a successfully operating adaptive organization with authoritarian controls.

2. RXD Flourishes When the Group Enjoys Consensus-Collaboration Relations With its Sponsors

Consensus-Collaboration and Coercion-Compromise are a pair of antithetical terms closely related to the pair adaptive and authoritarian. They are particularly applicable to the relations and communications between a pair of individuals or groups. The most obvious characteristics of these systems are shown in Table V-4.

A typical coercion-compromise system is based on authority and obedience relationships. Behavior is controlled by the exercise of power and the invoking of a system of rewards and punishments.

In a typical consensus-collaboration system, the prevailing relations are those of trust and mutual confidence. Control is achieved through agreement on goals and values, coupled with a communication system which provides continuous feedback so that the members of the system can steer themselves.

We examined the environment of RXD Event No. 93 for evidence of consensus-collaboration or coercion-compromise relations between the NOL development group and the Bureau of Ordnance. This was done at the same time and in the same way that we searched for evidence of authoritarian or adaptive organization; we found that the evidence for consensus-collaboration relations was even more one-sided than the evidence showing a local adaptive environment. Applying this experience, we found as before that well-identified relations usually fall closely into one pattern or the other but not into a mixed pattern. In 11R and 38XD Events the relationship between the R&D group and its sponsoring organization could be described as a consensus-collaboration relation. In 14XD Events, the relation is better described as a corecion-compromise relation. In 10 of these 14, a well-defined informal channel also existed which supplemented or largely replaced the official channel of communications between the sponsor and the executor of the research and exploratory development. Thus, a significant open communication channel existed in 61 of 65 Events.

The data purport to show two instances of corecion-compromise relations where consensus-collaboration relations did not exist between sponsor and executor, and where the initial stages of work were privately funded. A more detailed examination of the sources shows that the desired sponsor and the ultimate beneficiary was the Department of Defense, that the failure to gain initial support was one aspect of the lack of consensus-collaboration relations, and that private funds were tapped for initial support rather than to let the project die.

Several factors were cited as bases for a consensus-collaboration relationship. The most frequently mentioned, in decreasing order of incidence, are:

Long personal associations between the parties (3R, 21XD)

Attention of both parties focused primarily on the goals of the effort. (4R, 19XD)

Strong technical insight on the part of both parties (8R, 14XD).

In 8R and 46XD Events, knowledge of the need was communicated informally to those who responded with the idea to satisfy it, rather than by a formal document or briefing. In many cases, we know there was give and take in both directions; we believe there was give and take in most. Only in four XD Events was the event conceived by the sponsor and communicated primarily through an RFP, an ADO, a GOR, or some other formal mechanism. In all 11R and in 37XD Events, the promoter of initial support of the work was closely identified with those who conceived the ideas.

The scientists and engineers involved in the innovation have in almost every case had past experience working on military problems. Often this provided them with a knowledge of military requirements equal to that of the Department of Defense. Furthermore, this familiarity permitted them to work with the military in arriving at final military requirements through a process of iteration, and this iteration was clearly a positive factor in many cases.

In 2R and 16XD Events there was some evidence that the Department of Defense resisted innovation by turning down or ignoring some program for carrying out these events or their substantial equivalents. Six of these were among the 14XD Events where no consensus-collaboration relation existed between the RXD group and the sponsors. In 2R and 17XD Events, direct contact between the group doing RXD and the Defense Department showed evidence that the Defense Department was acting in the way expected of an authoritarian organization rather than an adaptive organization. Of these, eight were among

the 14XD Events in which no consensus-collaboration relation existed between the R&D group and its sponsors.

Thus, from several points of view the open informal communications in a consensus-collaboration relation show superiority over restricted formal communication of a coercion-compromise relation. This finding is consistent with other facts suggesting that an adaptive environment is more desirable than an authoritarian environment for the execution of research and exploratory development. The expression of needs and goals, the dissemination of knowledge about them, bilateral discussion of goals and objectives, and the self-organization of activity toward fulfilling them are prominent parts of the mechanism by which an adaptively organized group gets its work done. For adaptive control to work, the group must be in a postion to discuss goals and progress, and to learn how their work fits into a larger scheme. In an authoritarian system, the top management has the responsibility for dividing the problem into small tasks, and specifying those tasks so that subordinates can carry them out by following orders handed down from above. Free discussion of goals, objectives, problems, and progress is not part of such a management system. "Theirs's not to make reply; theirs's not to reason why; theirs's but to do or die."

Based on these findings, it is recommended that the Department of Defense attempt to maintain consensus-collaboration relations with its research and exploratory development contractors, government laboratories, and other agencies carrying out R&D on their behalf. However, while such a recommendation is easily made, it will be much more difficult to carry out than the recommendation to maintain an adaptive environment for research and exploratory development. It will be difficult because one party in these relationships is the branches of the Defense Department, which may see no good reason for overthrowing the standards of their normal authoritarian organizational system and the coercion-compromise relations which they have with other groups. Outside of R and D, the normal relations between the Defense Department and its contractors (or between an agency and a subordinate group), encourage clear boundaries in authority, responsibility, and scope of activity. Controls are invoked which are intended to discourage deception, to punish failure, and to ensure that work meets pre-established specifications.

However, as we have seen, this kind of relation is inappropriate for the encouragement of research and exploratory development, and the Defense Department should be prepared to suffer the pains of internal organizational disruption to avoid such relations with research and exploratory development units. It should, as a minimum, recognize where consensus-collaboration relations already exist, and avoid upsetting them with authoritarian controls. It should avoid defining fixed channels for communication and restricting its

content. It should invite bilateral discussion of goals, values, needs, problems, and attitudes as well as facts; it is particularly desirable to invite serious discussion of the Defense Department's important needs and objectives and the circumstances under which needs are felt. It should avoid fragmentation of authority and responsibility, such as using separate channels for technical and for contractual negotiations. It should avoid a superordinate-subordinate relation, and should invite R&D people to discuss failures and errors under circumstances where everyone can profit from the experience rather than in circumstances where punishment is feared.

In summary, the Defense Department should abandon its claim to superior authority and its prerogatives for making or passing on all decisions when dealing with R&D people. The claim of superior knowledge is invalid, and good R&D people will not long tolerate the exercise of authority by outsiders whose knowledge they do not respect. On the other hand, after fear has been allayed, scientific personnel will welcome without prejudice the cooperation of anyone, including those dedicated and committed exclusively to the Defense Department, who can make a positive contribution toward worthwhile objectives. It is to the Defense Department's advantage to be seen as helpful cooperative servants to R&D personnel, rather than as firm-minded masters, no matter how just or fair.

3. Laboratories, People, and Compensation.

Eleven R and 36XD Events took place in laboratories where our rating of the laboratory director was good or excellent. In most of the remaining instances, none of our senior participants was personally familiar with the laboratory director or his work; we assumed in these cases that the man did not have a distinguished reputation and tabulated a neutral response. The standard is subjective, but the staff members who participated in this evaluation have participated in hundreds of research projects and management studies, and have seen a large number of program managers under circumstances where their performance could be judged to be poor, fair, good, or excellent.

Ten R and 43XD Events were done in organizations which already had or were rapidly developing reputations for first-rate development activities. In ten of the R Events, the principal contributor had a distinguished professional reputation at the time the event occurred; this was true for only 21 of the XD Events, although many have acquired such reputations since. These facts suggest that success in exploratory development does not depend so heavily on outstanding people.

The laboratory director is in a good position to build the kind of adaptive environment in which an innovator can flourish. By teaching, persuasion, and mediation, he can establish an environment which encourages new ideas, and make funds and resources available for initial exploratory efforts. Newborn ideas are tender and fragile, and do not survive transplantation or delay.

Another important function of the laboratory director and the laboratory management is to sustain desirable consensus-collaboration relations with sponsoring agencies. The director and his policy-level assistants are in a good position to deal freely and directly with high-level people outside, and to gain direct knowledge about needs, goals and objectives. At the same time, they can sell the ideas from their laboratory and show reasons why their staff members can be expected to do a good job in development. They can use their prestige, influence, and external contacts to bolster formal and informal communications.

Even good laboratory directors, however, did not always succeed in maintaining open communications. We heard from several former laboratory heads that they felt remote from top managment in the Pentagon and that their laboratories were too far removed from the mainstream of the Defense Department's activity. Some who have left Government service cited this among their reasons for leaving.

One aspect of the management of laboratories not previously mentioned is the observation that in 10R and 45XD Events the conceivers of the idea remained involved in the execution of the research or exploratory development. This may be regarded as an aspect of motivation, as evidence for the adaptiveness of the local organization, or as evidence against rigid boundaries between various categories of research and development or between various functions served by members of a team doing exploratory work.

It has been conjectured that the personalities of creative people differ significantly from those of most of their associates. We were in no position to undertake personality profile studies, but we did undertake to inquire whether the behavior of any of the principals in these RXD Events was seen as outside the range of behavior considered fitting, proper, or normal in the organization. Charles Steinmetz was used as an example to illustrate is meant by a man whose behavior is outside the normal range for his organization, but who is nevertheless welcomed as a productive member of the group. We found only eight Events (7XD, 1R) where such unusual personality traits stood out.

This could mean any of three things. First, it could mean that the kind of innovative activity represented by our population of events is not

correlated with unusual traits of personality and behavior. It could also mean that all of these organizations have screened their membership quite effectively, irrespective of the expectation of innovative contributions. Or it could mean that people with innovative personalities (if there is any such thing) have found adaptive organizations where their behavior is compatible with the organization's expectations.

The matter of compensation was approached obliquely. Most of our interviews were unstructured and we put no limitation on the subject matter. A wide variety of subjects concerned with morale, motivation, technical achievement, transfer of personnel, and so forth were introduced into the conversation, but we never introduced salary into the conversation. Surprisingly, none of our respondents ever mentioned it either. We can only conclude that men working on successful exploratory development projects within the environment of a well-managed laboratory have a feeling that their efforts are being recognized and that management is treating them fairly as far as compensation is concerned.

It is recommended that the Defense Department continue to weigh the reputations of laboratory directors and laboratories as important evidence in considering how to allocate resources. Most of the previous recommendations, and probably other desirable policies not uncovered in this study, can be implemented in part by finding laboratories of high repute and delegating a large part of RXD planning and management to the laboratory director and his staff.

4. Field of Work

In gross terms, these events fall in the fields of chemistry, electrical engineering, mechanical engineering, metallurgy, physics, and rocket propulsion engineering. No more than 20 percent nor less than 10 percent, of the Events fall in any of these broad fields.

Looking at the field of activity on a smaller scale, we found that the field in which the Event occurred was changing rapidly at the time the Event was initiated in 7R and 36XD Events. Furthermore, interdisciplinary stimulation within the organization was important in the conception and execution of ten of the R and 29 of the XD Events. These two observations, and the difficulty which we had in making a unique assignment of field of science or technology to many of the Events, suggests that RXD activity does not naturally fall into mutually exclusive fields of science and technology.

It is recommended that the Defense Department plan its research and exploratory development program with the recognition that worthwhile RXD is frequently interdisciplinary or occurs in a field which is rapidly changing.

The boundaries among fields of science and technology should not be allowed to constrain RXD activity.

D. UTILIZATION OF RESEARCH AND EXPLORATORY DEVELOPMENT

The median delay between the completion of an RXD Event and its incorporation in system development is around one year for an XD Event and five for an R Event. Twenty-three Events were incorporated within one year, and 12 Events waited five or more years to be utilized. This distribution of times is shown in Appendix E.

Informal communications are just as important in the utilization of XD Events as they are in their initiation. In 33XD Events, papers, patents and written reports were not an important mechanism in bringing about first utilization of the event. However, they were an important mechanism in all 11R Events. Nevertheless, in all 11R Events (and in 42XD Events) utilization was brought about (in part at least) by a person who is closely identified either with the conception or with the execution of the event.

The relative timing between the initiation of an RXD Event and the initiation of the system development in which it was used shows a wide spread. The median R Event was initiated five years before system development, and the median XD event two years before, but 11XD Events were initiated after system development had begun on the system in which they were used. This distribution is biased in both senses. On the one hand, long time delays (greater than 12 years) were eliminated because we did not look at RXD Events initiated earlier than 1945. On the other hand, the standard for acceptance or rejection of a particular description as a valid RXD Event depended to a certain extent on its relation to needs and to sponsors, and several possible RXD Events were rejected largely because they were initiated substantially after system development was undertaken, and were tainted with the suspicion that they were engineering aspects of operational system development rather than exploratory development. The resulting distribution is shown in Appendix E.

We find that informal personal communications are an important contribution to the utilization of an RXD Event. A small proportion of Events have a built-in market, for they are stimulated by a need arising in the system development which ultimately utilized them. It is recommended that the Defense Department provide for informal personal communication of RXD accomplishment as well as for publication and distribution of papers, reports, and patents, and that the Department recognize that a significant number of worthwhile innovations are initiated only after a need for them has arisen in a system development.

E. SYNTHESIS OF AN IDEALIZED PATTERN OF A RESEARCH AND EXPLORATORY ENVIRONMENT

Most of the propositions in the previous section can be interrelated in one idealized environmental pattern. At the center of the pattern is the research group itself. This should be constituted so that it functions according to an adaptive system. In addition, it must accept a goal or a mission, it must have resources at its disposal, and it must be capable of generating ideas.

The mission and goals which are communicated should have as few constraints as possible consistent with the accepted value scheme. That is, what should or should not be done should be governed by considerations of what will and what will not be useful or worthwhile. Constraints which are not related to the ultimate goal and mission and which arise from values not appropriate to the goal and mission should be removed. There should be a value scale related to the goal and mission, in such a way that the value of various ways to approach the goal can be estimated and compared. Understanding of the goals should be sufficiently general that any action bringing one closer to the goal will be considered valuable.

Usually, a hierarchy of goals is required. The most specific goal forms a basis for judgment and decision making, and the most general is directly related to ultimate values and motivation. The relation between specific goals and general goals and values is not constant. The value of a technical approach may depend on the availability of alternatives, the value of the solution to a problem may depend on its timeliness, the acceptability of a weapon systems concept may depend on the climate of national or international opinion, and so forth. Means for establishing and re-establishing this connection must be provided.

Control in the adaptive environment is achieved by diffusing and understanding of missions, goals, and values sufficiently widely so that locally made judgments about what is worthwhile and what is not, what should be done and what should not, are consistent with the dominating scheme of goals, mission, and value. This is in contrast with the authoritarian system, in which a well-defined system exists for making decisions at one place and disseminating them. Inasmuch as the relation between the very specific goals required for everyday decision making and the over-all goals is not static, this diffusion must be repeated or continuous. This makes communications necessary, both within the organization and between the organization and the ultimate source of motivation.

Within the adaptive group, the appropriate type of communications is part of a general pattern of organization. Between the group and the ultimate source of motivation an open communication channel is called for. It should be possible to pass both information and attitudes and opinions in both

directions through this channel. Every time new knowledge or new insight is developed, it must be possible to check decisions against the most general scale of values, and conversely to derive an improved set of limited goals from the general goal and mission. The result of this process is to reestablish trust based on community of values and on agreement that the course of action being undertaken continues to be worthwhile in terms of the over-all goal and mission. This process also serves to reinforce commitment to both the limited and the general goals and mission. Needless to say, rewards and penalties, both material and psychological, should be consistent with the goals, missions, and values as seen by everyone concerned.

Insofar as the ideas to be exploited are new and original, they cannot be specified ahead of time. But partly systematic methods of problem solving have been described. Polya(4) suggests that the three most important methods of finding ideas for problem solving are by analogy, by generalization from special cases of the same type of problem, and by specialization from more general cases. For these methods to be accessible, the researchers should be familiar with more general and more specialized problems of the same type and with analogous problems. This suggests that the people on whom we depend for innovative ideas should be people actively engaged in problem solving and in innovation in fields related to the goal and mission. Common sense suggests further selection on the basis of past success.

The character of the resources needed will be defined by the missions, the limited goals, and the type of ideas which it is intended to exploit. The amount of resources desirable is derivable, in principle, from the values, which can be derived from the general goals and missions. An obvious way to assure the availability of resources is to let them be built up as part of the same activity which leads to the development of sources of ideas. To the extent that branches of the Department of Defense operate according to an authoritarian system, the ambiguous authority, responsibility, and status implied by consensus-collaboration relations would cause discomfort. There seems to be no reason to ask that the Department of Defense abandon its traditional organization solely to foster research and exploratory development. The existing organization seems to work for most of the Department's purposes. Therefore, communication with innovation-producing research and exploratory development activities must be somewhat restricted, and should be channeled through to agencies capable of maintaining consensus-collaboration relations. From the point of view of those doing the exploratory work, it is desirable to arrange things so that these channels can be used as though they were entirely open links to the whole Defense Department. In particular, few limitations should be put on the kind of communication which moves in either direction; transmission of motives, feelings, and attitudes should be encouraged; the subjects of change in the Department of Defense and how it

might be brought about should be allowable topics of communication; and control by reward and punishment, encouragement and threat, should be avoided in favor of control by communicating values, pooling information, and seeking a consensus on the most desirable course to undertake.

It is obvious that this model incorporates in their broad outlines of many of the findings of Sections B, C and D above. We believe it is consistent with all the Findings and Recommendations, although entirely unrelated to some.

F. DIFFERENCES BETWEEN RESEARCH AND EXPLORATORY DEVELOPMENT

The presently accepted definitions of research and of exploratory development distinguish between effort directed toward the solution of problems with no clear direct military applications, and effort directed toward the solution of specific military problems. A number of factors may blur the distinction.

In the first place, exploratory activity may be motivated by more than one purpose. The man who is actually doing the work is likely to have different motives from his laboratory director and from his sponsor, and is therefore likely to disagree with them about what is really research and what is really development. Here we are inclined to honor the research worker's judgment over that of his sponsors and supervisors.

Secondly, the clarity and directness of a military application is a subjective judgment which may be strongly colored by the degree of understanding both of the projected exploratory activity and of the circumstances in which a military application might be made. Once again, the man doing the work is likely to have a different view from that of his supervisors and sponsors; but in this case, we are inclined to give more respect to the latter.

Third, the present Defense Department definitions do not mention nonmilitary problems and nonmilitary applications. Insofar as these definitions are used by managers to place programs into fund categories, the omission is reasonable. But the end use of exploratory activity may be an application not anticipated when the work was done, and some of our examples (e.g., RXD Event 20, quoted in Appendix B) are clearly examples of exploratory development aimed at filling nonmilitary needs and solving nonmilitary problems. It is plausible to generalize the Department's definitions simply by omitting the word "military" wherever it occurs. To insist on rigid, mutually-exclusive definitions of research and exploratory development is an

invitation to argument. However, if we agree that the distinction is not absolute and that a unified activity may partake of both qualities, we can usually distinguish them.

The biggest source of confusion concerns the goals, missions, and objectives of research. Insofar as research does not anticipate any particular application, it may not be possible to derive a set of research goals and objectives directly from military problems, needs, missions, or objectives. The Defense Department's program planners and managers may derive from military needs, missions, and objectives, a sufficient basis for initiating and supporting one or another kind of research; their deliberations may tell them what areas of science to support, what kind of people to sponsor, and what kind of institutions to place their work in. But when they have made these decisions, they will not ordinarily try to motivate the groups they support by showing, in those terms, why the work is important to the Defense Department. The people who do research develop motives, purposes, and objectives of their own.

In nine examples of research, the chief motivation can be directly related to two of three essentials we find for the initiation of exploratory work: generating a source of ideas and generating a pool of resources. To this extent, research can be indirectly related to military needs. Planning of this kind of research could be enhanced by asking what kinds of facilities and what kinds of instruments are potentially useful in exploratory development, what kinds of problems would we like to know how to solve, and what kinds of knowledge would we like to have.

As observed above, exploratory development activity is very likely to be triggered by the emergence of a particular expression of a need. This may be a new need caused by a change of circumstances, a need which is perceived for the first time because of some new knowledge, or an old need which is restated in such a way that it stimulates action. Research can also be triggered this way, but may have much more diffuse motivation, such as the conviction on the part of the principal investigator that his field of research is important and interesting or that it may have social and economic significance in the future.

When this diffuse motivation exists, it is probably irrelevant to test it for rationality. Although not every man with a dream is likely to make a great contribution to science and technology, it appears that certain kinds of contribution to science and technology are only made by men with dreams. Therefore it is improper to eliminate research activity or deny support because of such motivation; if work of this nature is to be supported at all, it is probably wrong to use the character of the dream as part of the basis for decision. In

summary, some research workers do work which is important to the Defense Department for reasons other than the solution of military problems and the fulfilling of military needs, or the attainment of military objectives. Support of this kind of work should be based on an estimate of its ultimate contribution to the Defense Department, not on an evaluation of the investigator's motives and goals by evaluators committed to military objectives and endorsing the Defense Department's values.

III. RESEARCH AND EXPLORATORY DEVELOPMENT ORIGINS IN SIX WEAPON SYSTEMS

A. INTRODUCTION

The results of our examination of six weapon systems, which have been reported more fully elsewhere, are summarized in the nine sections below. These are intended to be brief summaries for easy reference, and may not be fully self-explanatory. In each case an attempt has been made to display in graphic form a historical tree showing a main stream of development which contributed to one of these systems, leading back to origins in exploratory activity. The particular innovative research and exploratory development activities which we have identified as RXD Events are indicated on these trees. Thus, these show the time sequence of the RXD Events, the interconnection of RXD Events and other research and development activity into connected progressions, the weapon system subsystems, circuits, devices, and materials which benefited from these progressions of research and development, and, in most cases, the personnel involved in the RXD Event or the institution in which the work was done.

Two things are immediately obvious from these graphical presentations. First, there are very few spectacular "key" Events, technological breakthroughs, or other innovations which could be described in dramatic terms. The bulk of the innovations were relatively minor, and seem in retrospect quite uninteresting. Originally, we were determined to find RXD Events of great importance, and tended to ignore avenues of investigation which would turn up only relatively routine activity. The spectacular Events failed to materialize in large numbers, and we now realize that the number of unspectacular RXD Events could have been multiplied considerably if the study had been carried out with more modest expectations. In fact, the study of the Bull-Pup Missile carried out by the DDR&E steering group adopted such a point of view, and unearthed proportionately a much larger number of RXD Events.

A second observation is that the RXD Events contributing to a particular weapon system development are spread over a long period of time. The actual time spread is underestimated in these charts, for we made no particular attempt to carry our historical efforts back more than twenty years. Indirectly, this shows that there is no well defined research phase or exploratory development phase in the history of the development of these particular weapons systems. This point is further emphasized by later evidence showing that a significant proportion of exploratory development activities only take their definitive form after problems arising in later stages of system development, or even in operational use, have to be faced.

B. XM-102, 105MM HOWITZER

The XM-102 Howitzer was designed as a lightweight and therefore air-transportable weapon capable of firing extended range ammunition.

Early in our study of this system it became clear that most of the research and development supporting the system design had been performed prior to 1946. Also the Technical Development Plan for the system required that previously proven subsystems be used. Thus practically all of the work which went into the XM-102 was engineering development and design based on research work carried out prior to the time period of our study.

We found two RXD Events which, although not undertaken directly for the XM-102, did provide a technical input. These are #75 (Gun Tube Erosion Inhibition), and #78 (Autofrettage Swaging).

Most of the research and development since World War II connected with field artillery support has been on rocket-assisted projectiles or short-range missile systems. In a well developed field such as conventional artillery, only incremental and evolutionary improvements can be expected--mostly in materials--since the technology is well understood. There has also been some development effort in new techniques and manufacturing procedures. The one example connected with the XM-102 Howitzer is described in RXD #78 (Autofrettage Swaging).

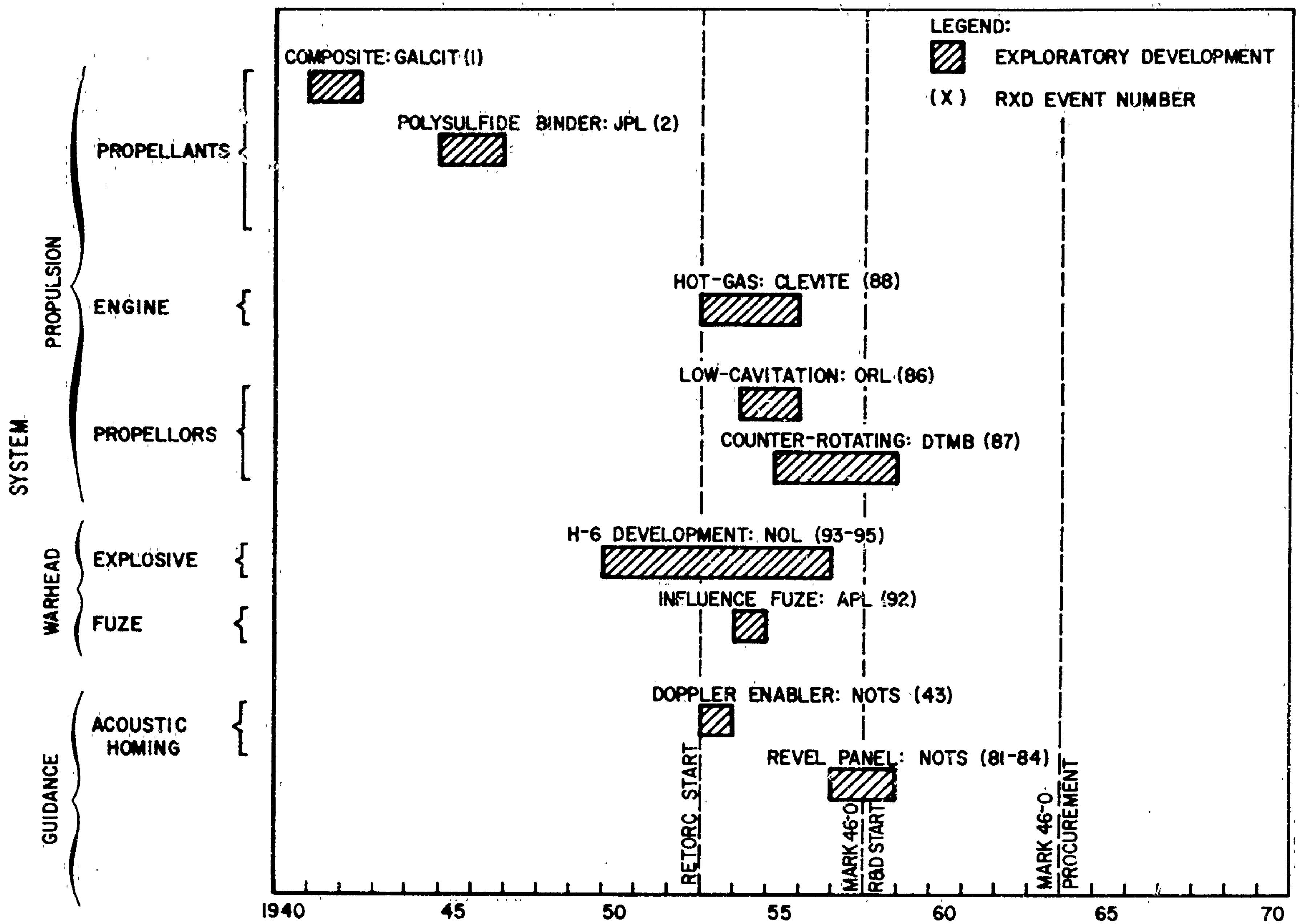

FIGURE III-C DISTRIBUTION OF MARK 46-0 TORPEDO RXD EVENTS BY TIME AND LOCATION

C. MARK 46-0 ACOUSTIC HOMING TORPEDO

Figure III-C shows the time relationship of the RXD Events used in the Mark 46-0 torpedo weapon system. Also shown is the duration of each event, where it occurred, and the identifying number assigned to it.

Vertical dashed lines show three important events in the chronology of the Mark 46-0 torpedo; the establishment of the Retorc I concept, the start of the Mark 46-0 development contract, and the first production contract. The Retorc I concept, a lightweight torpedo, was conceived by C. Sandler of BuWeps in 1953 and assigned to NOTS. This administrative move, not actually formalized until 1960, was of material assistance since it provided a means for integrating the results of torpedo supporting research and development programs into a weapon with a minimum of interface problems.

The mission of the Mark 46-0 torpedo is to home on and kill a high-performance, deep-running submarine from a surface or air launch. This required a major improvement in existing torpedo capability. The significant developments which made this possible were as follows:

1. An Efficient, Safe, and Reliable Fuel

The Mark 46-0 was the first torpedo to use a solid propellant as a fuel. As noted, the exploratory development on the grain consisted of improvements by JPL on the early World War II JATO work at Cal Tech (RXD Events #1, 2). The exploratory development was completed before the Clevite engine was conceived.

2. A Lightweight, Low-noise, High-horsepower Engine

The engine design was based on a completely new approach. H. Hamlin of Clevite developed a hot gas, swash plate engine. The noise level of this engine was low, and it could operate under high back pressure for deep operation. The engine exploratory development was supported by Clevite and was completed before the start of the Mark 46-0 contract (RXD Event #88).

3. Low-cavitation Propellor

An increase in torpedo speed puts increasing demands on the reduction of propellor cavitation noise. A successful demonstration of a low-cavitation noise propellor was made in 1955, one year after serious work began (RXD Event #86).

4. Counter-rotating Propellors

DTMB was familiar with ORL work and foresaw the possible need for developing a design theory for counter-rotating propellors to ease shaft loads and gain efficiency. Exploratory development, using "free" funds resulted in computer programs for rapid design (RXD Event #87). DTMB completed the MK 46-0 propellor design in 1959.

5. Improved Explosive

A continuing program to improve air and underwater explosives at NOL resulted in the development of the H-6 explosive for maximum air blast in 1950-52 and the later recognition of its desirable high shock energy characteristics for underwater use, permitting a 15-25% improvement in explosive power on a pound-to-pound basis (RXD Events #93, 94, 95).

6. A Reliable Fail-safe Exploder

A continuing research program on torpedo exploders at APL permitted this laboratory to develop a short-range influence fuze to permit reliable torpedo detonation (RXD Event #92). The exploratory development began in 1954 at BuOrd request and was completed in 1955, three years before the Mark 46-0 contract was let.

7. A More Sophisticated Guidance and Homing System

In order to lengthen acquisition range and improve search volume rate, a vastly better receiver-transmitter-transducer package was needed. The conceptual synthesis and exploratory development of a system (the Revel Panel) with significant processing gain improvement was completed in 1958 at NOTS about the time the Mark 46-0 contract was let (RXD Events #81-84). The initial work on an important aspect of the Revel concept was also done at NOTS in 1953 (RXD Event #43).

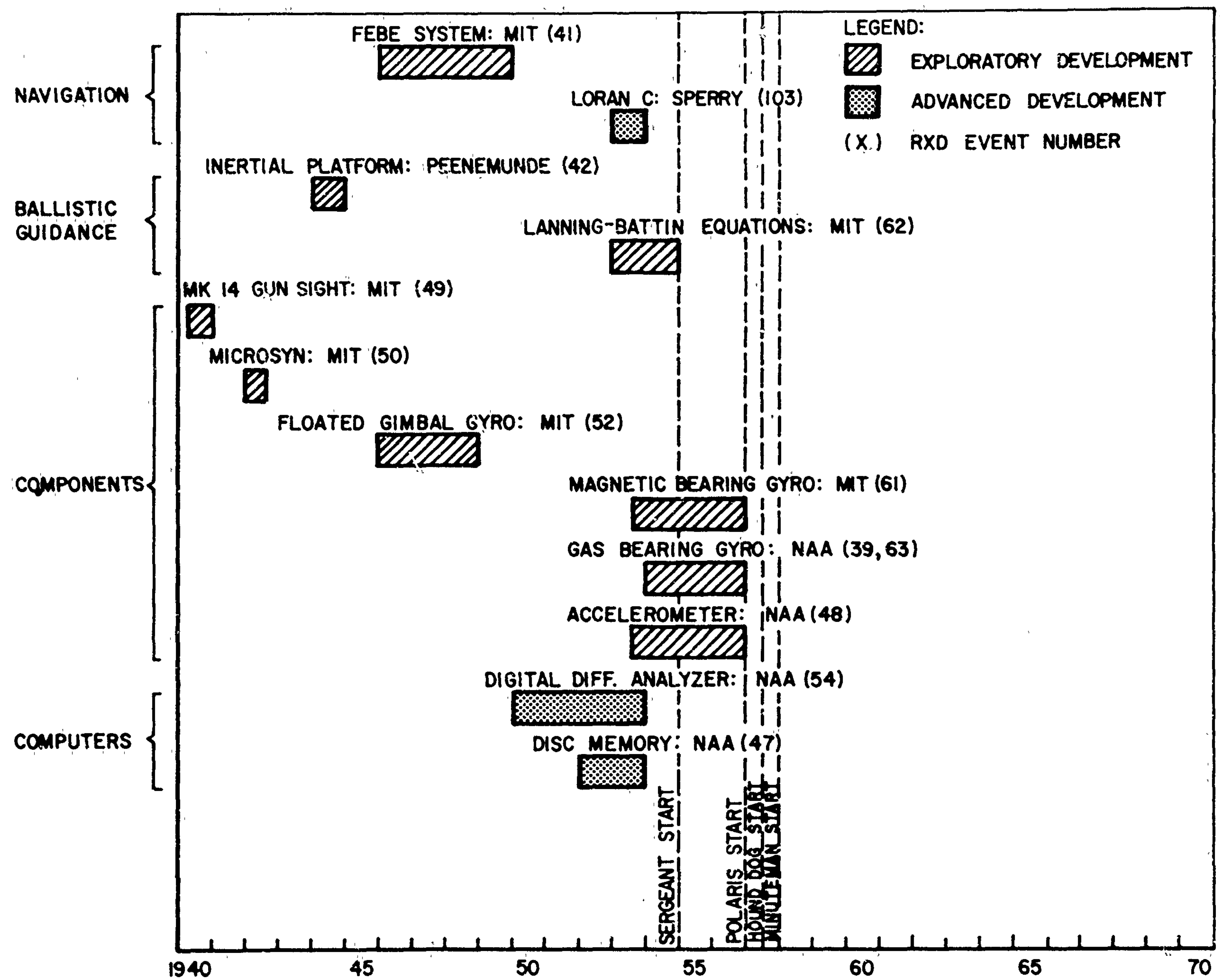

FIGURE III-D DISTRIBUTION OF INERTIAL GUIDANCE AND NAVIGATION RXD EVENTS BY TIME AND LOCATION

D. INERTIAL GUIDANCE AND NAVIGATION

One of the basic requirements for the use of a ballistic missile from a mobile platform is a navigation system capable of accurately locating the platform at the time of launch. Once launched, the missile requires a self-contained guidance system capable of controlling its flight during the powered phase.

Most of the development work done in the United States on the subsystems which were critical to the success of navigation and inertial guidance systems was concentrated on components for sensing angular and translational motion and on computers which operate with the sensing systems to establish position and compute steering orders.

Figure III-D shows the distribution of time and location of the principal RXD events which contributed to the development of inertial guidance and navigation systems.

1. Navigation

The development of inertial sensing systems for navigation began with the gyrocompass, invented by Anschutz in Germany around 1908. Working with Anschutz, Schuler showed how the gyropendulum could be made insensitive to horizontal accelerations. His paper on the subject, which appeared in 1923, presented a scheme by which a gyrostabilized element, which could track the direction of true north in response to the accelerations induced by the rotating earth, could also track the local vertical in response to the acceleration of gravity, undisturbed by horizontal accelerations (RXD Event #96). This inertial system configuration anticipated fundamental system characteristics appearing in the experimental FEBE system built at M.I.T. in the late 1940's (RXD Event #41), and in the Hound Dog and Polaris submarine navigational systems as built by North American Aviation, M.I.T., and Sperry Gyroscope. The Polaris submarine navigation system employed a precise fix-taking system which involved a significant improvement upon the LORAN system developed during World War II. It utilized higher frequencies and phase-matching of the two range measuring signals and employed sky- as well as ground-wave propagation (RXD Event #103).

2. Ballistic Guidance

Between World War I and World War II, Germany developed inertial guidance for ballistic rockets. Germany's inertial systems evolved through a number of configurations, culminating in one which appeared late in the war, and involved a platform isolated from vehicle motion by gimbals and servomotors, and stabilized by three single-degree-of-freedom gyroscopes (RXD Event #42). A pendulous integrating gyroaccelerometer measured velocity along the trajectory and terminated propulsion when the desired velocity was reached. In the method of platform stabilization, this German system anticipated major features of platform configuration in all of the weapon systems under discussion. The gyroaccelerometer anticipated that used in Polaris, and the whole system accurately anticipated those appearing in the Sergeant, Polaris, and Minuteman missiles.

With the initiation of long-range ballistic missile work in the United States, a system of computing steering corrections based upon celestial mechanics was suggested and developed at M.I.T. and applied first to Thor and later to Polaris. This system represented a significant improvement over the straightforward extension of the German artillery-based system to longer ranges (RXD Event #62).

3. Component Development

Important contributions to gyro art began at M.I.T. early in World War II with the development of gyroscopes with improved capabilities to sense angular rotation and compute lead angles for antiaircraft guns (RXD Event #49). A related development was the microsyn, an extremely precise electromechanical transducer capable of measuring shaft rotation or applying precisely measured torque to a shaft (RXD Event #50). This component later was an important element of the integrating rate gyroscope developed at M.I.T. shortly after World War II, and leading to orders of magnitude improvement in gyro accuracy (RXD Event #52). Only one gyro has appeared since this development which competes with it in accuracy and departs from it fundamentally. That is the free gyro developed by North American Aviation eight years later, in which the gyrowheel is freely supported in a spherical gas bearing (RXD Event #39). The basic features of the M.I.T. gyro are employed in the Sergeant, Polaris, and Hound Dog systems. The North American free gyro is employed in Minuteman.

The M.I.T. gyro was significantly improved upon by North American, concurrently with its development of the gas-bearing supported free gyro, when the company developed journal and thrust bearings with gas as the lubricant for the spin axis of the M.I.T. gyro (RXD Event #63). This led to improvements in accuracy and life which were important to the performance of the Polaris submarine navigation system.

A further improvement in the M.I.T. gyro became possible when a means of simply supporting the gyrogimbal by magnetic forces was discovered in 1953 and subjected to fairly continuous development before incorporation in the gyroaccelerometers used in the Polaris missile guidance system (RXD Event #61).

A basically different accelerometer from those used by the Germans during World War II and which has characteristics superior to all except the best gyroaccelerometers, was developed at North American during the company's extremely productive period in the middle 1950's. This device employed pendulous torque servobalanced against an eddy current torque induced by rotating a permanent magnet, shunted by the pendulum, about the pendulous axis. The resulting device yields directly a measure of the velocity through which it has been accelerated, which data are of primary importance in any inertial guidance or navigation system (RXD Event #48). This form of accelerometer is used in Hound Dog, Minuteman, and the Polaris submarine navigation system.

4. Computer Development

The other major area of the United States' contribution to inertial guidance technology is in the computers which integrate the angular displacements of the vertical in an inertial navigation system, and which integrate velocity in an inertial guidance system, in order to establish vehicle position. In the guidance systems, steering orders are computed as well. North American began work on digital computers for this purpose in the early 1950's and by 1954 had demonstrated both the feasibility and the superiority of digital differential analyzers (rather than analog differential analyzers) for these functions (RXD Event #54). A significant element of these digital computers was the high-speed magnetic-disc memory supported by a gas bearing (RXD Event #47). These computers and memories are used in the Hound Dog and Polaris submarine inertial systems. The Polaris missile uses a similar computer developed later at M.I.T., whereas Minuteman uses a digital computer which is less closely related to the first North American digital differential analyzer, but retains some features of the earlier computer for certain critical functions.

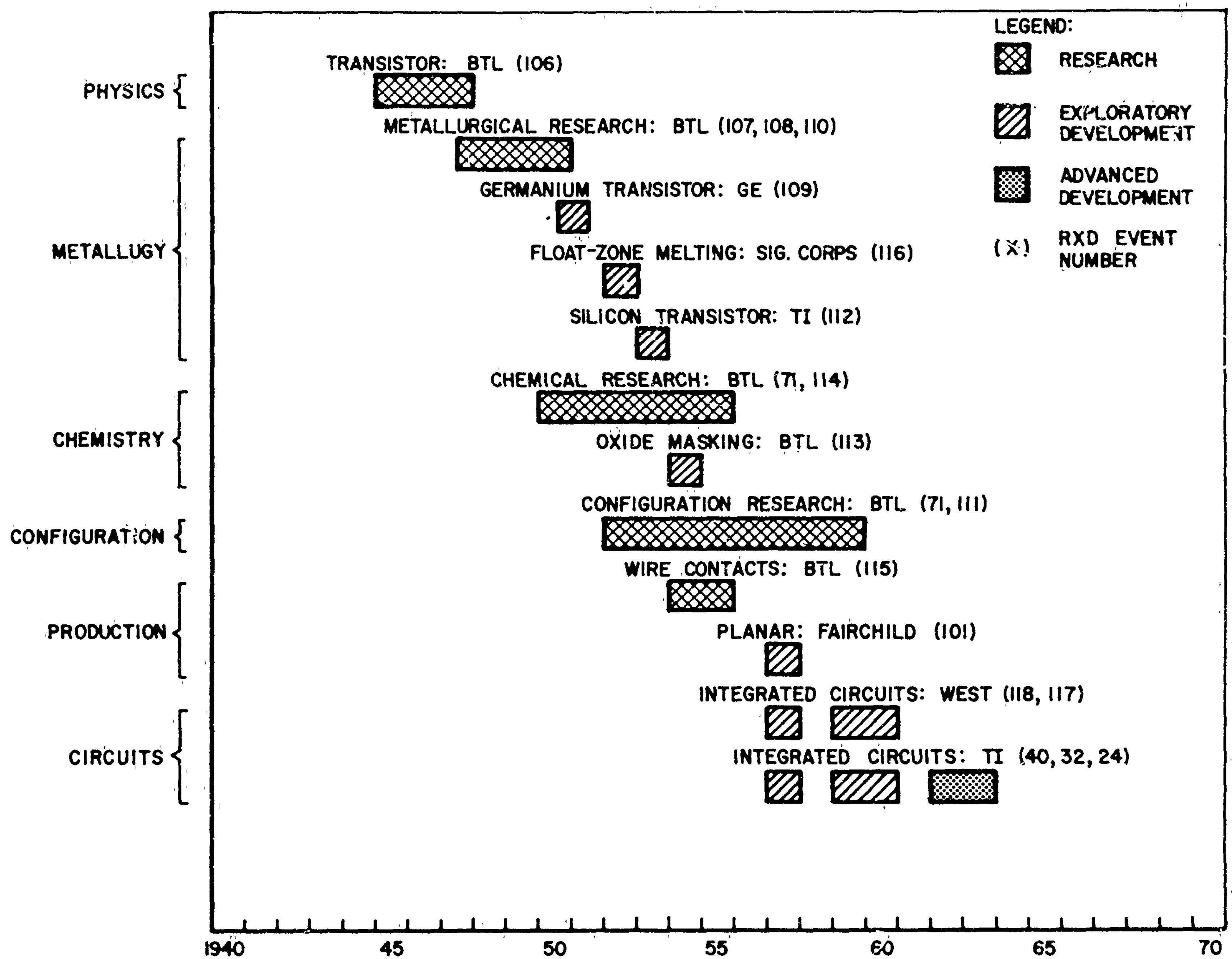

FIGURE III-E DISTRIBUTION OF TRANSISTOR AND OTHER SOLID STATE DEVICES RXD EVENTS BY TIME AND LOCATION

E. TRANSISTORS AND OTHER SOLID-STATE DEVICES

Out of a number of research accomplishments which led to discovery of the transistor, and a much larger number of RXD Events which followed, we have chosen a few of the more important ones which contributed to major classes of transistors used in the weapons systems studied. Figure III-E illustrates their relationship. These Events are noted at the time interval of their occurrence, ordered by the field of research, development, or fabircation to which the RXD was particularly applicable. Table II relates the RXD Events to significant steps in the process of making four of the many types of transistors being used in the weapons systems studied.

It will be noted that after the research in solid-state physics leading to the discovery of the transistor, the utilized events came in turn from the fields of metallurgy and chemistry, followed by research and exploratory development utilized in improved geometrical configurations, production fabrication, and circuitry.

Transistors have had a great influence on modern weapons system development and effectiveness. Most of the weapons systems studied, particularly Sergeant, Hound Dog, Polaris, and Minuteman, depend greatly on solid-state devices, amplifiers, and switching elements in their electronic circuits, especially in the subsystems for guidance and navigation. These systems have all benefitted by the progress achieved over the last 20 years from solid-state devices, and many of the RXD Events pertinent to transistors have been applicable to all.

The transistor, due to its light weight, small size, low power consumption, low cost, and high reliability, has provided weapons systems with a considerable computational and functional capability. Since a substantial portion of the cost, weight, and space of the aircraft, weapons systems, and even satellites of today is occupied by the electronic subsystems, it seemed pertinent to conduct a separate investigation into the solid-state devices used in weapons systems, and into solid-state devices and transistors in general. We have done this by examining the RXD Events directly applicable to types of solid-state devices in major use; an outline of additional related RXD Events in the solid-state field is presented in Appendix C.

TABLE III-1

FOUR TRANSISTOR PROCESSES FOR FABRICATING TRANSISTORS USED IN WEAPONS SYSTEMS

1. Germanium Alloy Transistor
(example - 2N404 used in Polaris)

Zone Melt Germanium (#110)
Grow Single Crystal (#108)
Cut wafers and etch
Alloy Indium Junctions (#109)
Alloy Base Contact (#107)
Etch, encapsulate, etc.

2. Silicon Grown Junction Transistor
(example 2N117-120)

Grow Silicon Crystal (#108)
Grow Silicon Transistor (#112)
Cut bars and etch
Alloy Base Contact (#107)
Etch, encapsulate, etc.

3. Germanium Mesa Transistor
(Example 2N559 used in Nike)

Zone Melt Germanium (#110)
Grow Single Crystal (#108)
Cut slices and etch
Diffuse Base Layer (#114)
Alloy Base, Collector Contacts (#107)
Etch Mesa, cut up wafers
Wire-Bonded Contacts (#115)
Encapsulate, etc.

4. Silicon Planar Transistor
(example 2N1613, etc., used in Minuteman)

Float-Zone Silicon (#116)
Grow Single Crystal (#118)
Cut slices and etch
Epitaxial Deposition (#71, #111)
Oxide Mask (several) #113)
Diffuse Planar Process (#114, #101)
Alloy Contacts (#107)
Cut up and assemble
Wire-Bonded Contacts (#115)
Encapsulate, etc.
Check reliability

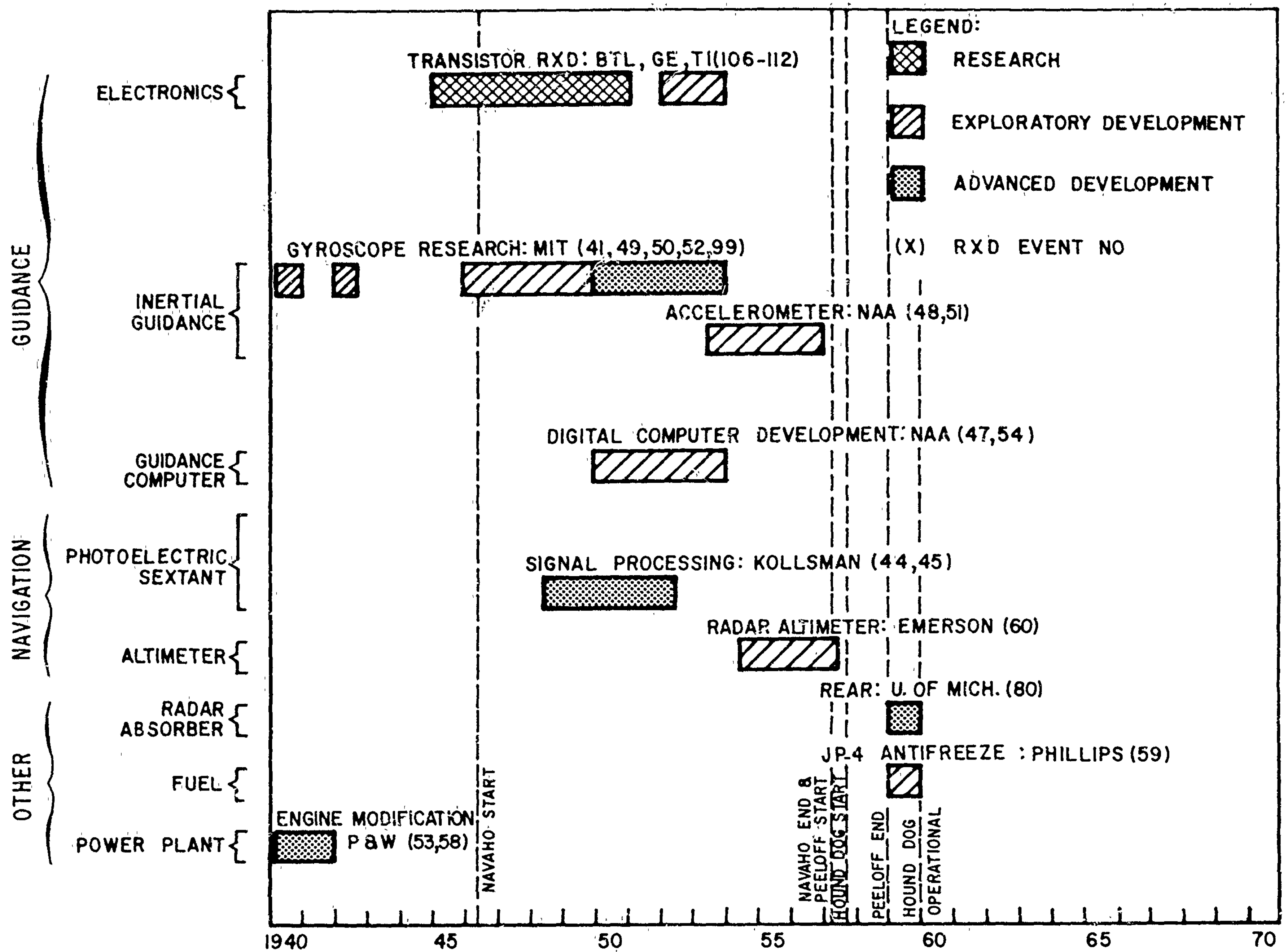

FIGURE III-F DISTRIBUTION OF AGM-28 HOUND DOG RXD EVENTS BY TIME AND LOCATION

F. AGM-28 HOUND DOG AIR-TO-GROUND MISSILE

The Hound Dog is a jet-propelled, air-to-ground missile carrying a nuclear warhead and incorporating a stellar-monitored, all-inertial guidance system. It became operational early in 1960. The missile operates in either high subsonic or supersonic flight modes and is capable of both high- and low-level attack patterns. It weighs less than 12,000 pounds, approximately one-half the weight of its immediate predecessors. This reduction in weight, accomplished at no sacrifice in performance, was made possible by two significant advances in technology - the lightweight nuclear warhead and the all-transistorized digital computer. The sequence of RXD Events that was used in the Hound Dog missile is shown in Figure III-F.

Many of the RXD Events identified as being significant to Hound Dog were associated with the development of the Verdan digital computer and with the accompanying inertial guidance platform. Both of these subsystems were developed at North American Aircraft's Autonetics Division during the period from 1950 to 1957 and were ready for use in the Hound Dog when that program was funded.

Autonetics drew at various times upon the work of the German group of rocket technologists at Fort Bliss and upon the work of Draper and others at M.I.T.'s Instrumentation Laboratory (including RXD Events #41, 49, 50, 52 and 99).

Autonetics' work on the digital differential analyzer (RXD Event #54) began in 1950 in conjunction with the Navaho program with the primary objective of reducing the size of the inherently larger analogue computers then in use. A vacuum tube version of this computer, called the NATDAN, was built in 1955, employing a disc magnetic memory (RXD Event #47) that contributed greatly to compactness and reliability. The relationship between the RXD Events in the area of inertial guidance and navigation is shown in more detail in Section III-D.

The silicon transistor became generally available in 1954 through work at Texas Instruments (RXD Event #112) and was assimilated into the Verdan and other systems at Autonetics. In this way, RXD Events #106, 108, 109, 110, and 111 also were used in the Hound Dog. These events and their interrelation are discussed in Section III-E. Although the Navaho program was canceled early in 1957, North American was able to continue work on the most promising guidance concepts under an extension called "Project Peel-Off." This program provided the continuity between Navaho and succeeding systems and allowed the completion of GN-5 inertial platform in time for Hound Dog. This system incorporated a greatly improved pendulous integrating accelerometer (RXD Event #48), and a means for converting the information provided by the platform components into digital form for processing in the navigational computer (RXD Event #51).

The ability to operate at any time of day and in any part of the world was assured by the development of the twilight astrotracker at Kollsman Instrument Co. (RXD Event #44). This development was one of a series of astrocompasses emanating from a 15-year RXD #8 program at Kollsman, which began with the first demonstration that a star could be automatically acquired and tracked by a telescope and included the development of a unique shutter scanning and raster-chopping system for processing the optical signal received by the instrument (RXD Event #45).

Among the several components available at the time Hound Dog was authorized was the radar altimeter developed by Emerson Radio and Phonograph (RXD Event #60). This instrument provided the high reliability required for the low-altitude attack mode that was a part of Hound Dog's mission.

An operational problem in the B-52 gave rise to RXD Event #59. In order to prevent deterioration of the plane's fuel tank linings by the anti-icing additive then used, Phillips Petroleum Company developed a compatible antifreeze that is now used in nearly all JP-4 fuel. Since the Hound Dog uses the fuel of its mother plane, the B-52, this event was utilized in 1959 when the first missiles were flown.

A series of developments in microwave absorber technology at the McMillan Labs made available a microwave absorbent material compatible with the structural, thermal, and electronic requirements of the Hound Dog. In 1959, it became apparent that survival of the Hound Dog was threatened by its high radar cross section, and Professor Siegel of the University of Michigan's Radiation Lab was asked to develop and define an absorber configuration to reduce that cross section. Siegel accomplished this (RXD Event #80), and a subsequent program of materials testing resulted in the selection of McMillan's material for use on the Hound Dog.

The power plant of the Hound Dog is the Navy's J-52 turbojet engine, modified for application to the missile's mission. The requirement for supersonic and subsonic flight modes necessitated the design of a two-position spike diffuser for the engine inlet (RXD Event #58), and also generated an interesting innovation in control system design (RXD Event #53).

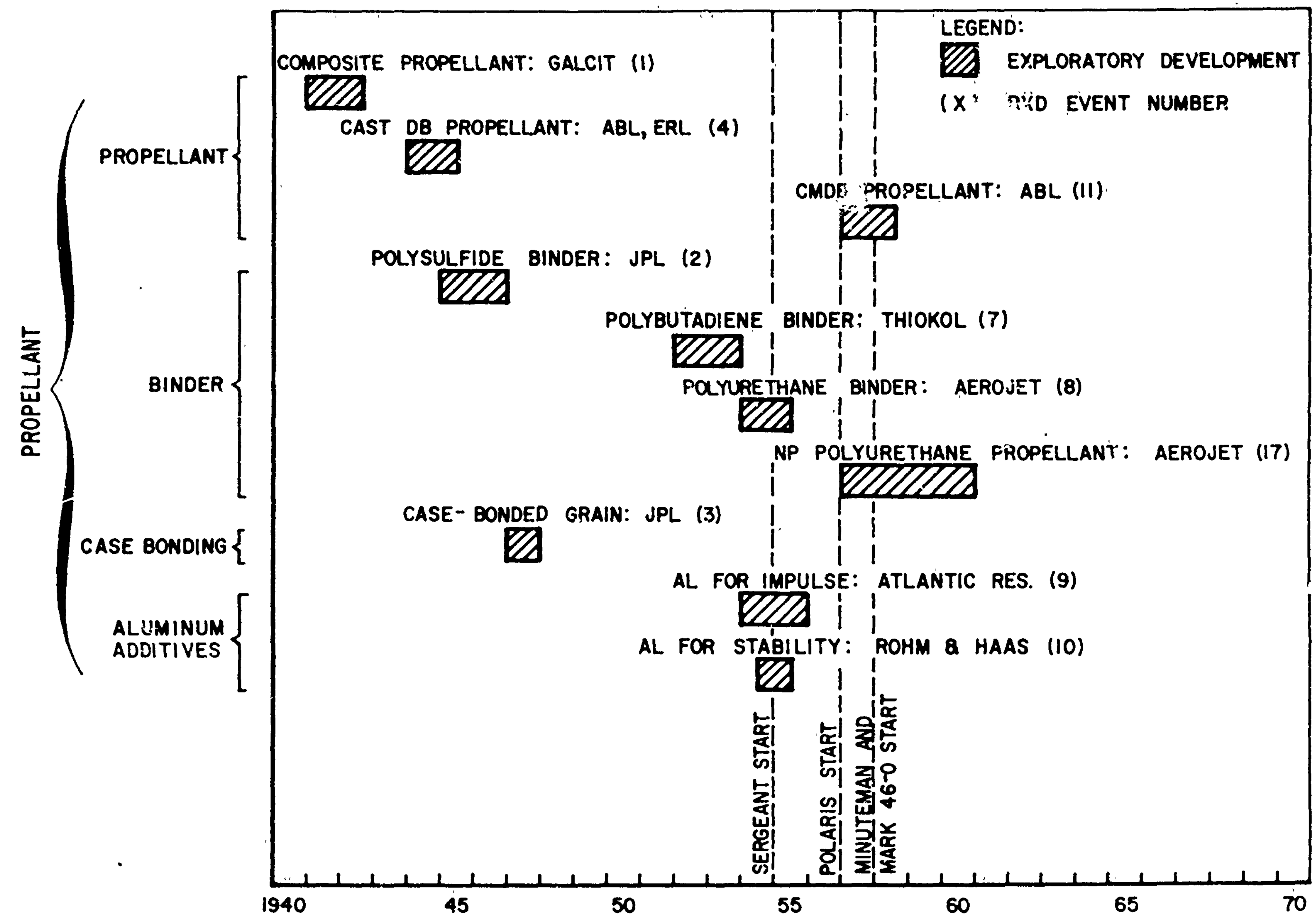

FIGURE III-G-1 DISTRIBUTION OF SOLID PROPELLANT RXD EVENTS BY TIME AND LOCATION

G. SOLID PROPELLANT ROCKETS

In our examination of the Mark 46-0 torpedo, Sergeant, Polaris, and Minuteman weapons systems, we found that all drew on a common background of solid propellant technology. Much of this technology was not associated directly with the specific weapon system development. Thus we found it simpler to examine solid propellant technology *per se* before relating it to specific systems.

Serious development of solid propellant rockets in the United States began at the beginning of World War II and has progressed rapidly from the Bazooka and JATO units of that time period to the monolithic motors being tested today. This development has provided in part for the deployment of a large number of successful weapon systems.

For this discussion solid rocket technology can be divided into three areas: propellants, controls, and materials.

1. Propellant Development

Figure III-G-1 shows the relationship between the major technical advances contributing to the development of high-performance propellants for ballistic missiles. This work was done at six different organizations.

a. Propellants

There are two major types of propellants: the double-base or homogeneous propellant; and the composite propellant, for which the oxidizer is present as a dispersed particulate phase. A search for a solid propellant rocket with a long burning time led GALCIT (now JPL) to develop the first composite propellant consisting of asphalt and potassium perchlorate (RXD Event #1). This propellant was first used in JATO units and later in experimental free-flight units.

Extruded double-base propellants originated in England and were adopted in the United States for use in tactical weapons. In 1944 the Explosives Research Lab (Bureau of Mines) originated and developed a method of casting double-base propellants which made their use in large rocket motors possible. Further work was carried out at the Allegheny Ballistics Laboratory (RXD Event #4).

In 1958 workers at the Allegheny Ballistics Laboratory developed a new propellant by incorporating composite ingredients in a double-base binder. The composite-modified, double-base propellant provides the highest specific impulse of any solid propellant available today and is used in the upper stages of Polaris and Minuteman (RXD Event #11).

b. Binders

The composite propellant binder normally acts as fuel and working fluid for the solid rocket and also serves to provide mechanical strength to the mixture. In the postwar years solid propellant development continued at GALCIT (now JPL) resulting in a composite propellant with a polysulfide resin substituted for the asphalt binder. The polymer improved the physical properties of the propellant, thereby increasing motor reliability and allowing the use of higher-energy oxidizers to improve performance (RXD Event #2).

In 1954 a polybutadiene fuel-binder was developed at the Thiokol Chemical Corporation. Binders of this type offer improved physical and chemical properties over the polysulfides; they are used in large quantities today (RXD Event #7).

In 1955 the first of a series of polyurethane fuel-binders was developed at the Aerojet-General Corporation. The polyurethanes also provided improvements over the polysulfides and have been used in many weapon systems (RXD Event #8).

A nitroplasticized polyurethane propellant which was recently developed at the Aerojet-General Corporation provides improved physical properties over earlier polyurethane propellants and is cured at ambient temperatures. The latter characteristic allows simplification, and hence weight reduction, in the motor case (RXD Event #17).

c. Case Bonding

Early rockets were loaded with separate propellant cartridges, and motor cases were exposed to high-temperature combustion products. The availability of the polysulfide fuel binder at JPL led to the development of a case-bonded propellant grain design. Case bonding permitted the use of lightweight, high-strength materials for case fabrication. The case needs only to be capable of standing the chamber pressure during burning, the propellant providing insulation until burning is complete (RXD Event #3).

d. Aluminum Fuel

In 1955 the Rohm & Haas Company discovered that the addition of small quantities of powdered aluminum to a propellant composition would eliminate combustion instability in the motor. In 1955 the Atlantic Research Corporation found that aluminum also provides a significant increase in specific impulse. These two discoveries led to the rapid development of aluminized propellants for use in high-performance motors (RXD Events #9, 10).

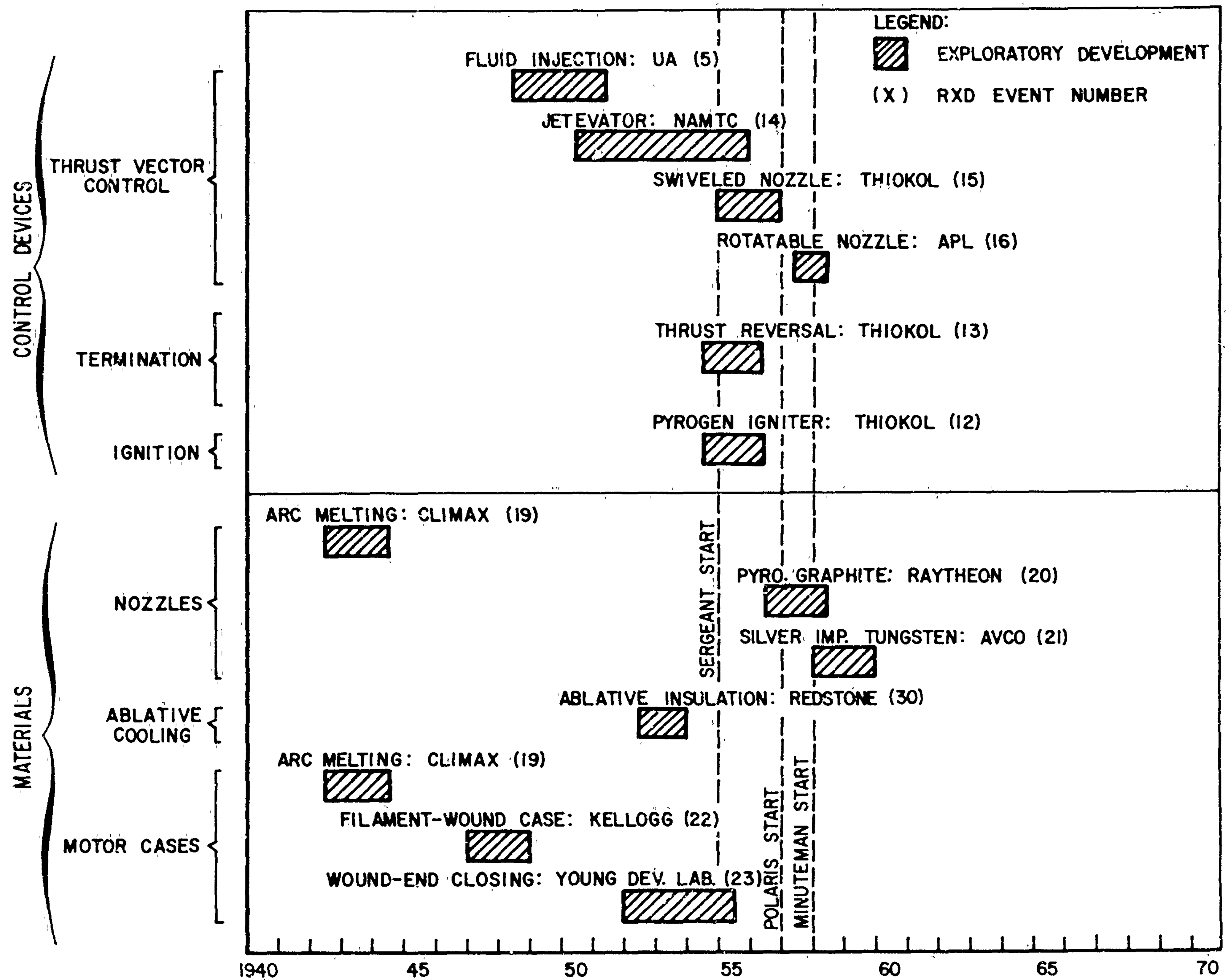

FIGURE III-G-2 & 3 DISTRIBUTION OF SOLID PROPELLANT CONTROLS AND MATERIALS RXD EVENTS BY TIME AND LOCATION

2. Controls Development

Once the feasibility of solid rocket propelled ballistic missiles was established, there was an immediate need for control devices associated with their use. The events that we examined in our study are concerned with thrust control for steering, thrust termination methods for range control, and ignition. The relationship of these events is shown in Figure III-G-2 and 3.

a. Directional Control

The Sergeant uses jet vanes for directional control developed earlier for control of liquid rockets. When Polaris was initiated, new directional control methods were required. Fluid injection for thrust vector control was originally demonstrated at the United Aircraft Corporation between 1948 and 1951. However, the method did not gain acceptance until further study had been conducted at NARTC and NOTS. Subsequently a liquid injection TVC system was developed by Hercules for use in Polaris A-3 and another by Aerojet for use in Minuteman Wing VI (RXD Event #5).

In the early 1950's NAMTC developed the jetevator as a method of thrust vector control (TVC) in solid rockets. The method was developed further by Aerojet and utilized on Polaris A-1 and A-2 (S-1) (RXD Event #14).

Preliminary work on swiveled nozzles for TVC was conducted at Thiokol in 1956, and advanced development was undertaken later by Thiokol, Aerojet, and Hercules. Each of these contractors developed a swiveled nozzle for use in Minuteman (RXD Event #15).

In 1958 a canted, rotatable nozzle was conceived at APL and suggested for use on Polaris. The concept was adapted for use on A-2 by Hercules and on A-3 by Aerojet (RXD Event #16).

b. Thrust Reversal

Reversal (or neutralization) of thrust in a solid rocket was first demonstrated at Thiokol in 1956, using a method based upon ideas generated at JPL in 1952. This system has been employed by Aerojet and Hercules in the final stages of the Polaris and Minuteman vehicles (RXD Event #13).

c. Ignition

The conception and demonstration of the pyrogen igniter occurred at Thiokol in 1956. This type of igniter now is used in nearly all large motors and provides more reliable ignition, particularly at high altitudes (RXD Event #12).

3. Materials Development

As higher-performance rockets became necessary for ballistic missile propulsion, several new materials were needed. These requirements fell into two general categories: materials for structural parts not exposed to high temperature gases, and materials which could survive exposure to the rocket exhaust. The relationship of these events is shown in Figure III-G-2 and 3.

The consumable-electrode, vacuum arc-melting process has contributed significantly to the development of improved structural materials. The process was developed by Climax Molybdenum Corporation in 1944, and has been used to prepare high-grade steels and titanium for rocket cases, and molybdenum and tungsten for control surfaces (RXD Event #19).

Filament-wound motor cases were conceived and developed by R.E. Young during the period 1947 to 1956. The work was initiated at the M.W. Kellogg Company and continued at the Young Development Laboratory. The cases consist of glass fibers impregnated with a thermosetting resin, providing the highest strength-to-weight ratio of any material used today. The method has been used by Hercules for Polaris and Minuteman motors, and, more recently, by Aerojet for Polaris motors (RXD Events #22, 23).

The use of reinforced plastics for temporary shielding of surfaces under conditions of high convective heat transfer was first demonstrated in this country at Redstone Arsenal in 1953. The concept has been adopted and used widely by motor manufacturers for insulating internal and external surfaces of rocket motors (RXD Event #30).

A method of preparing pyrolytic graphite in a form suitable for use in the throat section of a rocket nozzle was developed by Raytheon in 1957. The method was utilized by Hercules in the development of nozzles for the Polaris A-3 motor (S-2) (RXD Event #20).

In 1960 Avco conceived of the use of a composite of silver or copper and tungsten as a material for rocket nozzle throat sections. The concept was developed by Aerojet and is utilized in Polaris A-3 (S-1) (RXD Event #21).

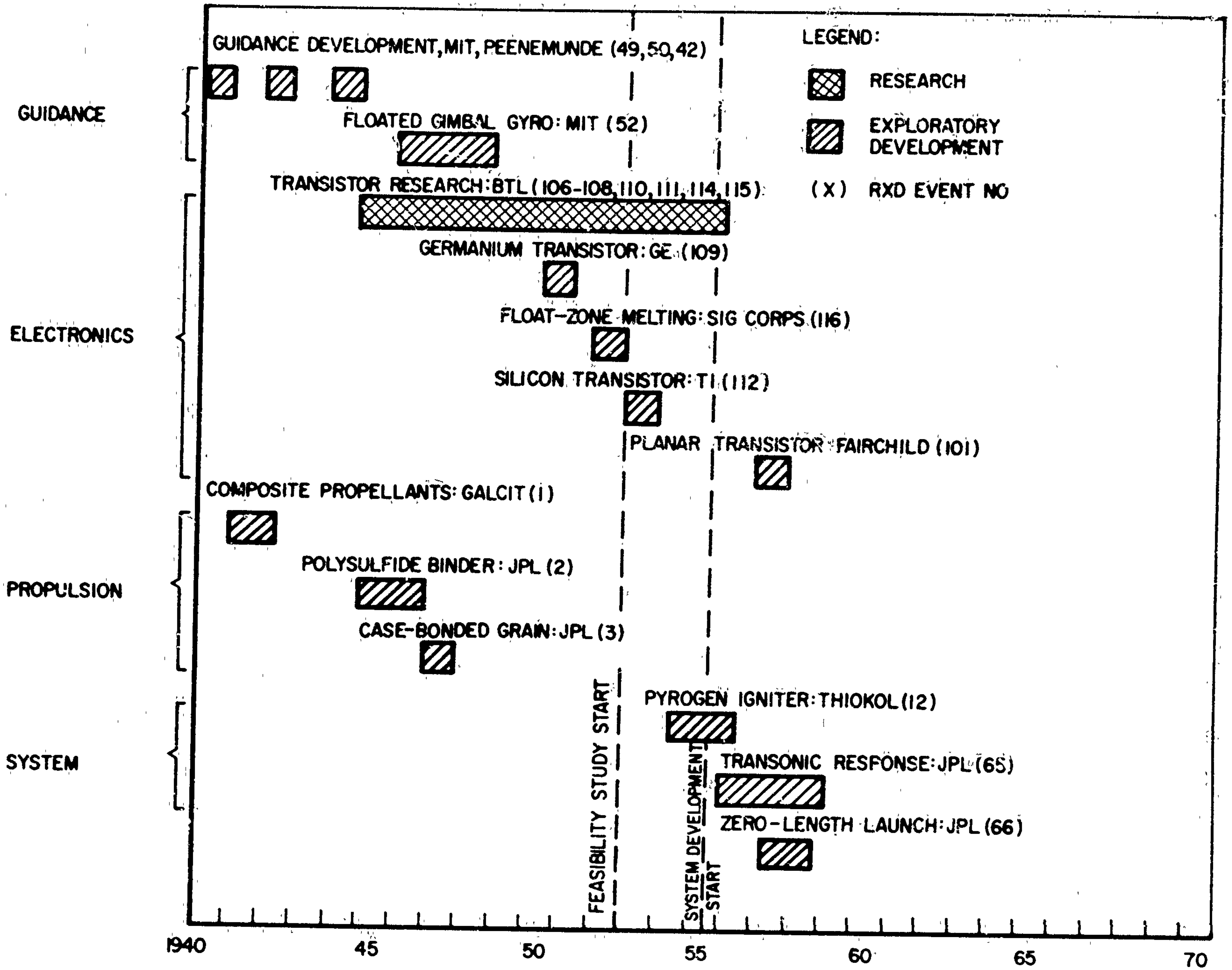

FIGURE III-H DISTRIBUTION OF SERGEANT RXD EVENTS BY TIME AND LOCATION

H. SERGEANT MISSILE

1. Background

The Sergeant missile development was based on work done at the Jet Propulsion Laboratory (JPL) on the Corporal missile and depended as well on the developmental work done on Hermes and earlier programs. The military requirements for a family of surface-to-surface missles later to become the Sergeant were first started in 1950. The Sergeant system was designed as a flexible tactical weapon system that would greatly extend the range of conventional artillery. The system was required to have high reliability, use a solid propellant, be immune to countermeasures, have a wide range coverage, be rugged, and be simple to operate and maintain. In April 1953, JPL submitted a preliminary design for such a missile and received a development contract in January 1955.

Figure III-H shows the time and location of the principal RXD Events for the Sergeant Missile system.

2. Guidance

The Sergeant guidance system was based on work done at Peenemunde and at the M.I.T. Instrumentation Laboratory. The missile guidance system was basically that developed at Peenemunde for the V-2 missile (RXD Event #42) but incorporating improved components developed at the M.I.T. Instrumentation Laboratory (RXD Events #49, 50, 52). The relationship of these Events is discussed in more detail in Section III-D.

The analog computer and control system used in Sergeant was based on the use of transistors. The relationship of transistor research and development is discussed in Section III-E (RXD Events #106 - 108, 110, 111, 114, 115). Later developments in the system used at Sergeant include the germanium transistor developed by General Electric (RXD Event #109), float zone melting (RXD Event #116), and the silicon transistor developed by Texas Instruments (RXD Event #112). Further improvements were made by the substitution of planar transistors as developed by Fairchild (RXD Event #101).

3. Propulsion

The Sergeant system uses a single-stage solid propellant rocket motor based on work at JPL and Thiokol. The motor, which is mounted in a steel case, uses a case-bonded, polysulfide composite propellant grain (RXD Events #1 - 3). The ignition system uses a pyrogen igniter developed by Thiokol (RXD Event #12). This work is discussed in greater detail in Section III-G.

4. System

The need for rapid setup time and simple maintenance was met by the use of a preprogrammed automatic checkout system. As a result of work at JPL the concept of a zero length launch system was developed (RXD Event #66). The missile range was controlled by the use of aerodynamic drag brakes. Initial instability problems with this concept were solved by JPL (RXD Event #65).

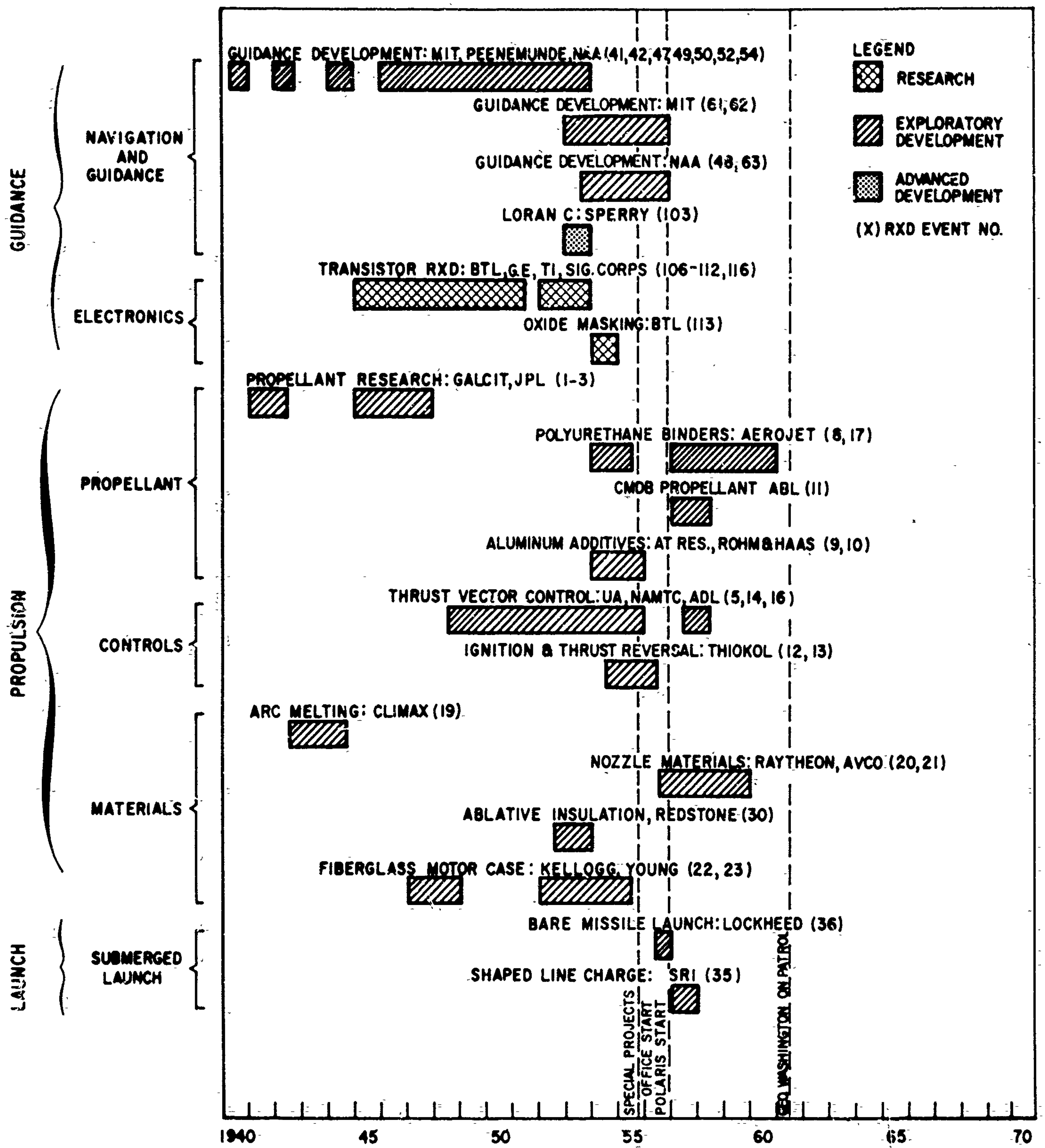

FIGURE III-I DISTRIBUTION OF POLARIS RXD EVENTS BY TIME AND LOCATION

I. POLARIS MISSILE

As recommended by the Killian Report in 1955, the Navy was given joint responsibility with the Army to develop a surface ship or submarine-launched IRBM. Early work involved an examination of the feasibility of a system based on the Jupiter liquid-fueled missile. After one year of investigation, the Navy was convinced that a much smaller solid-fueled missile was feasible and would be far more attractive than the Jupiter would be from a weapons standpoint. In late 1956, the Special Projects Office formally created the Polaris program basing its action on a number of bold assumptions concerning possible improvements in guidance, propulsion, and warhead technology that might be achieved by 1965. Within three months the Steering Task Group (STG), a high level advisory team, designed a basic system envelope. The first Polaris boat went on station 3-1/2 years later, 4 years ahead of the original plan.

By 1965 a third generation Polaris with approximately twice the original range and considerably more accuracy was available. These improvements were obtained with only minor modifications of the original envelope dimensions set by the STG in 1957.

Figure III-I shows the RXD Events used in Polaris for guidance navigation, propulsion, and launch. Either by request, or because they were not expected to contain many Events of interest, other areas were not studied.

1. Guidance

The accuracy with which the Polaris missile can be directed to a target depends on the accuracy with which the submarine position can be determined combined with the accuracy of the missile guidance system. As with Hound Dog, the Polaris guidance and navigation system was based primarily on the work at M.I.T. and North American Aviation.

The detailed relationship of the RXD Events on which these developments were based is discussed in Section III-D (RXD Events #41, 42, 47, 49, 50, 52, 54).

Several guidance Events were first used in Polaris. One of the more important was the development of the Lanning-Battin IRBM guidance equations which simplified the computer, the platform, and the vehicle flight dynamics (RXD Event #62). Another Event that was also developed at the M.I.T. Instrumentation Laboratory was the magnetic suspension gyro used in the accelerometers in the guidance system (RXD Event #61).

Two Events at North American Aviation also contributed to the Polaris submarine navigation system. One of these was the development of a gas lubricated bearing for the M.I.T. gyro (RXD Event #63). The other, first used in Hound Dog, was an improved accelerometer (RXD Event #48). In addition, the Loran "C" system developed by Sperry provided improved accuracy for submarine position location (RXD Event #103).

As was the case with all the missiles we have examined, the development of the transistor provided a basis for decrease in weight and increase in reliability in Polaris. The relationship of the RXD Events leading to the use of the transistor is discussed in Section III-E (RXD Events #106 - 112).

Transistors based on the use of oxide masking developed at the Bell Telephone Laboratories were first used in Polaris (RXD Event #113).

2. Propulsion

Polaris drew on the rapid postwar development of solid propellant rocket technology. Much of this work was also used in Sergeant and is discussed in more detail in Section III-G (RXD Events #1 - 3). A number of later Events were used in Polaris but not in Sergeant. In the area of propellants, the development of aluminum additives at Atlantic Research and Rohm & Haas for increased performance was of great importance (RXD Events #9, 10). Improvements over existing binders were made by Aerojet, which initially used a polyurethane binder (RXD Event #8), and later used a nitroplasticized polyurethane (RXD Event #17). The Allegheny Ballistics Laboratory developed a composite-modified, double-base propellant with the highest specific impulse of any propellant available today (RXD Event #11).

A pyrogen igniter was used in models 2 and 3 of Polaris (RXD Event #12).

In the area of flight control Polaris used a number of improvements over the method used by Sergeant. Several methods of thrust vector control (TVC) have been used, including fluid injection TVC, first developed by United Aircraft (RXD Event #5), the jetevator developed at NAMTC (RXD Event #14), and a canted, rotatable nozzle conceived by the Applied Physics Laboratory (RXD Event #16). Finally, the development of thrust reversal for range control at Thiokol was first used in the final stage of Polaris (RXD Event #13).

There were a number of developments in materials construction--vacuum arc-melting developed at Climax Molybdenum, was used to make both high strength steel and tungsten (RXD Event #19). Glass filament wound motor cases were first used on Polaris after their development at M. W. Kellogg and Young Development Laboratories (RXD Events #22 and 23). Raytheon and Avco developed materials for the throat section of nozzles - pyrolytic graphite at Raytheon and a silver-tungsten composite at Avco (RXD Events #20 and 21). Finally, the development of ablative cooling at Redstone was used as a basis for insulation of interior and exterior surfaces of the rocket motor (RXD Event #30).

3. Launch

When the STG developed the Polaris envelope parameters, the launch mode was not established. In fact, whether the missile was to be launched from a surfaced or submerged submarine was undecided. In the ensuing months, it became clear that the submerged launch was feasible. The basic missile launch concept, analysis, and test program was carried out concurrently with system development. It was not until late in 1958 that the final decision to use the bare missile launch was made (RXD Event #36).

One requirement of the bare launch system was that of a simple and reliable method of severing the diaphragm covering the launch tube. A line shaped charge was developed at Stanford Research Institute specifically for this purpose (RXD Event #35).

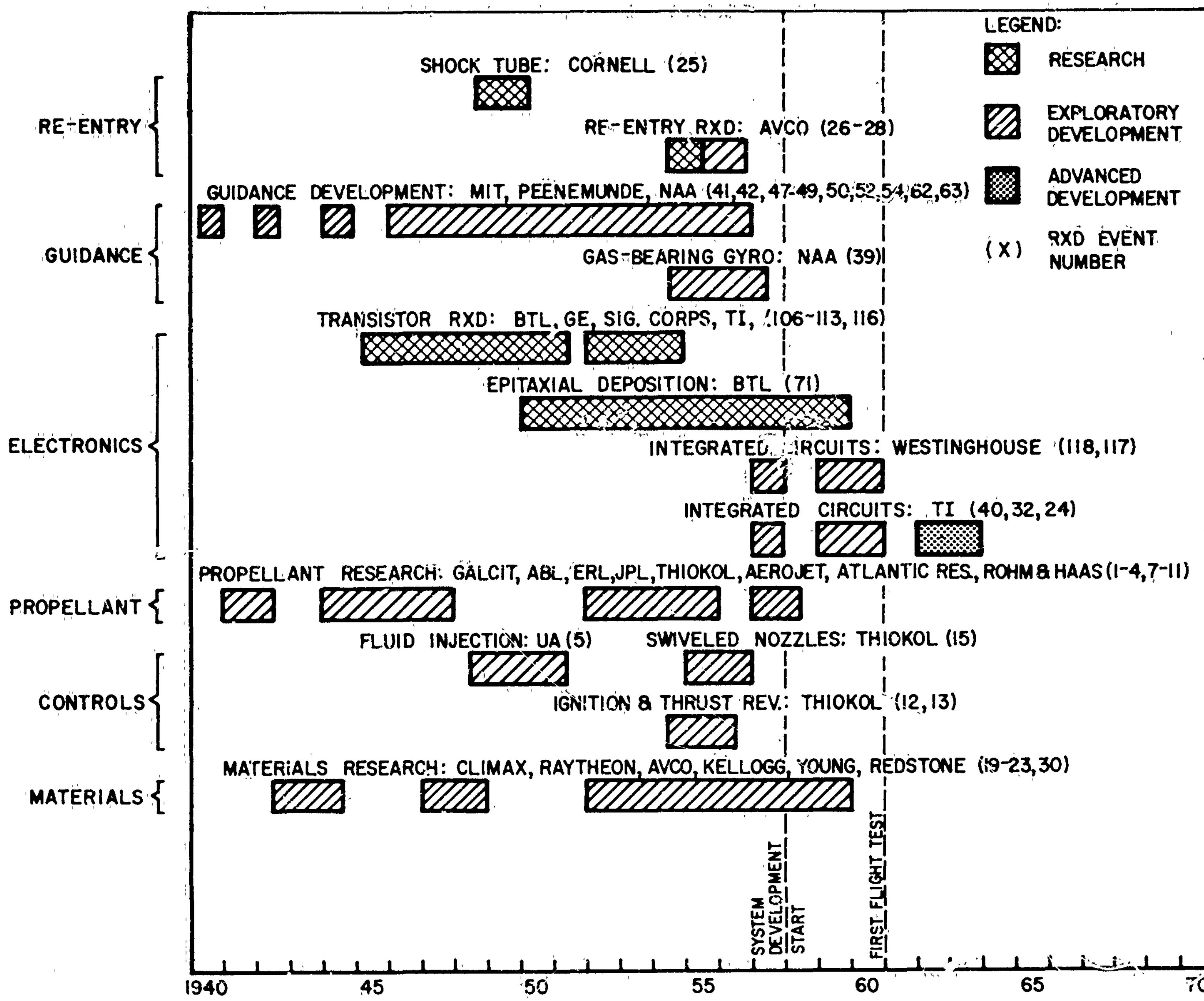

FIGURE III-J DISTRIBUTION OF MINUTEMAN RXD EVENTS BY TIME AND LOCATION

J. MINUTEMAN

1. Background

The Minuteman ICBM was superior to previous systems with respect to its reliability, hardness, simplicity, short reaction time, and high cost effectiveness. It was the first ICBM to use solid propellants with their advantages of long storage life and lack of on-site handling equipment.

System development started in February 1958 but was preceded by exploratory development, particularly in the field of solid propellants. Propulsion and guidance technology was based on Polaris, which preceded Minuteman by more than a year, while re-entry technology was drawn from Atlas and Titan.

Figure III-J shows the time and location of the principal RXD Events for the Minuteman.

2. Re-entry

Minuteman uses an ablative refractory nose cone to protect the warhead during re-entry. This system is primarily based on work at Avco-Everett. In 1949 and 1950 Dr. Arthur Kantrowitz of Cornell developed his high-temperature shock tube (RXD Event #25). This device was used in later efforts at Avco and GE to simulate re-entry conditions in the laboratory. As a result of this work it was possible to predict the behavior of various nose cone materials during re-entry. The aerodynamic behavior of a blunt nose cone was studied (RXD Event #26). Following this it was discovered that the heat-sink mode of re-entry vehicle cooling would be inadequate for ICBM warheads (RXD Event #27). Finally, a theoretical study of the behavior of specific materials under re-entry conditions predicted their behavior with good accuracy and resulted in the use of an ablative quartz shield (RXD Event #28). The Mark 6 nose cone used on Minuteman I was based on this work and an interchange of ideas between the parallel GE and Avco re-entry vehicle programs.

3. Guidance

The first inertial guidance system for a ballistic missile was developed at Peenemunde during World War II. This system accurately anticipated that appearing in Minuteman (RXD Event #42). Work in the United States since that time has been in the area of components which sense angular and translational motion and in the computers which operate with the sensors to establish position and compute steering orders. This work was concentrated at the M.I.T. Instrumentation Laboratory and North American Aviation (RXD Events #41, 47 - 49, 50, 52, 54, 62, 63). An event first used in Minuteman was the free gyro where the gyrowheel is freely supported in a spherical gas bearing (RXD Event #39). The relationship of the RXD Events in the area of guidance is more fully discussed in Section III-4.

4. Electronics

Success of the Minuteman system depends on reliability, simplicity and an assembly and deployment concept requiring centralized precision assembly and checkout. This concept has required a reliability level previously unattainable for the electronic subsystem.

The heart of the guidance system is an electronic computer depending on transistors for its operation. Early work on transistors at Bell Telephone Laboratories, General Electric, the Signal Corps and Texas Instruments led to the diffused-silicon transistors first used on Minuteman (RXD Events #106 - 110, 112 - 115). These were superseded by the planar transistors developed by Fairchild which permitted the reliability goals to be met (RXD Event #101). With the development of epitaxial processing and PNIP design at BTL, characteristics were improved still further (RXD Events #71, 111).

Recently, integrated circuits were developed by Texas Instruments and Westinghouse and applied to the guidance computer by North American Aviation (RXD Events #24, 32, 40, 117, 118). The relationship of these events is discussed in more detail in Section III-5.

5. Propulsion

Minuteman is a three-stage missile, each stage consisting of a single solid propellant motor. The propellants used draw on previous developments which appeared in Sergeant and Polaris (RXD Events #1 - 4, 7 - 11). The propellants in the first and second stages are aluminized composites while the third stage is a composite modified double-base propellant. Four swiveled nozzles, investigated first by Thiokol (RXD Event #15), are used for thrust vector control on each stage. In a later version, Wing VI, a single nozzle employing the secondary fluid injection TVC system is used in the second stage (RXD Event #5).

High-strength steel, titanium and filament-wound motor cases are used with tungsten nozzle throat inserts (RXD Events #19, 22, 23). Ablative insulation is employed in a number of locations both inside and outside the motors used in each stage (RXD Event #30). Stages A-2 and 3 use pyrogen igniters (RXD Event #12). The relationship between the propulsion RXD Events discussed here is given in greater detail in Section III-7.

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IV. CRITIQUE OF THIS STUDY AND RECOMMENDATIONS FOR FURTHER WORK

A. SUMMARY OF RECOMMENDATIONS FOR FURTHER STUDIES OF RXD MANAGEMENT

1. Further Case History Studies

This study has already shown that a historical method of studying case histories of development can lead to the identification of a large number of discrete exploratory development activities and some research activities. This particular point needs no further proof. The relatively low yield of Research Events compared with Exploratory Development Events is probably intrinsic in this methodology, but further study could probably show how to enrich the yield of Research Events.

This study has also shown that a large body of information can be generated about particular research and exploratory development activities of the past. Much of this information enlarges our understanding of research and exploratory development management, and suggests ways to improve it. However, the amount and range of data developed in the present study are small. Further studies are needed both to validate and to extend the results.

Many of the concepts introduced in this study are foreign to traditional management science and practice. Before the results of this and further studies can be implemented, it is necessary to admit the relevance of these concepts, at least far enough so that the data can be examined and talked about. It is recommended that future teams undertaking this kind of activity be made up largely of Defense Department personnel who expect at some time to be participating in and managing the Department's R&D programs. This method of team organization will be doubly profitable. The Department will get more data and more refined conclusions, and the investigators will gain personal experience which will augment this understanding and reinforce their commitment to new policies.

2. Failures

Further studies should examine research and exploratory development failures just as extensively as successfully executed and utilized RXD. A sample of failures is necessary to validate many of the conclusions of the present study.

3. Establishment of Objectives

Future studies on this subject should be aimed at the whole problem of attempting to improve research and exploratory development procurement in the Department of Defense, rather than at the limited problem of gathering data of a particular kind according to a particular methodology.

4. Relevance of Literature of Behavioral Science

By design, the present study was staffed by consultants experienced in carrying out and supervising research and development in engineering and the hard sciences. Behavioral scientists were excluded from central roles in the study. Before the study was completed, we adopted models and concepts from recent literature in the behavioral sciences to make a coherent interpretation of the data.

We are now convinced that the literature on innovation and research management in the behavioral sciences is valid as a source of ideas and observations in a study of this kind. Future studies should include experienced behavioral scientists as part of their professional staff.

5. Further Validation of Results

In addition to examining some failures to increase confidence in all the conclusions, other studies could be supported to validate some speculative results. Among these are the contrast in the role of goals and objectives in the initiation of exploratory development and in the initiation of research, a further examination of the way R&D groups use communications with the sponsoring agency when the sponsor will not support a consensus-collaboration relation, and various ways in which the DOD supports or resists innovation after research and exploratory development has been done.

6. Other Studies

The text of this report suggests a number of other areas in which interesting and fruitful studies of research and exploratory development management might be carried out. These include, for example, the relation between educational support programs and R&D productivity in the institutions sponsoring the programs; the growth and aging cycle of research and exploratory groups and institutions; and the question of how to identify the point at which a research and exploratory development activity ceases to be worthy of support, and how to transform it into a productive activity or dispose of it.

B. METHODOLOGY

1. Critique

During the course of this study a number of problems arose, some of which were solved with little difficulty, but some of which remain. This section is a brief review of those problems which are likely to recur if another study of this type is attempted.

The first problem is the ambiguity of the objectives of this study. The work statement is method-oriented, not goal-centered. It describes in considerable detail a sequence of steps to be carried out, with the implicit assumption that no uncertainties will arise, or that when uncertainties do arise it will be clear how they may be resolved. The only general objective is "to discover relations between the environment in which research and exploratory development projects are carried out and the extent to which these projects are subsequently exploited in operational weapon systems," which is in itself, a method-centered rather than a goal-centered statement. The discussion in Section V-C, concerned with the rationale of the identification of RXD Events, reveals that there are still unanswered questions quite significant to anyone attempting to carry out a study by this kind of method. Decisions based on an estimate of progress toward a broader objective are needed.

Another problem is intrinsic in the kind of historical survey we undertook. Our respondents are preoccupied with system development, and they are not vitally concerned with research and exploratory development. In many cases, they were ignorant of the actual degree of novelty of some of the innovations in their system. (In general, they tended to overestimate rather than underestimate the originality.) In other cases, their knowledge of the actual sources of the ideas was very sketchy. Among the community of scholars doing basic research at the frontiers of science, great importance is attached to correct attribution of sources. Among engineers, this is a matter of indifference except in cases of patent infringement. This appears to be a problem of cultural usage, not one intrinsic to the development of thought. For example, sculptors today are given specific credit for their art, but the writers of television scripts are given relatively scant attention; during the period when Greek culture dominated that of the civilized world, the Greek playwrights were closely associated with their works, but the sculpture was unsigned.

Even in more fundamental areas of exploratory development, we found most people uninterested in attempting to look back for the sources of their ideas. The methodology we used does not seem to be a particularly fruitful one by which to reach back all the way from application to fundamental research. It is relatively successful in going back to early stages of Advanced Development and to Exploratory Development.

The next problem is that research and exploratory development are hard to define uniquely. This question is taken up at length in Section V-C.

Another problem is that objective environment features, those which can be counted, measured, or identified numerically, appear far less significant than subjective properties involving attitudes, motives, and personal reactions. We believe that the objective rational environmental features have just as much significance as the others, but they are already fully exploited as means to improve research and exploratory development productivity.

Another problem is that the data which can be gathered are much too voluminous to reduce by routine methods. In one single environment study, one individual in ten working days and another in four working days gathered materials which, when transcribed, covered more than 30,000 words of interview transcripts. In addition, they accumulated many hundreds of pages of text, charts, and tables which were specifically related to the RXD Event they were studying and its environment. Until some principle was adopted to focus attention on particular features of these data, very little could be done with them. There is no hope that it will organize itself or even that such a body of data includes within itself a means for self-organization. This also makes it comparatively unrewarding to attempt to cleave to the original idea of writing an objective description of each environment.

The key to the reduction of massive data is insight and a good hypothesis. The environment descriptions are reduced to manageable proportions largely by adopting a point of view prejudiced by a hypothesis. It then becomes pedagogically more desirable to state the hypothesis and use parts of the environment descriptions as illustrations, rather than to attempt to organize the data so thoroughly that the hypothesis becomes obvious without being described. But the hypothesis no more springs out of the data than a theory of planetary motion springs out of celestial observations.

2. Limitations of the Methodology

Two important limitations in the methodology of this study have come to light. First, only successfully utilized research and exploratory development has been systematically studied. There is no control against which to compare it. Second, systems of research and exploratory development management which are not in common use have not been seen. These limitations are discussed more fully below.

From the beginning we have had the idea of comparing utilized research and exploratory development with research and exploratory development which is unutilized or which is unsuccessful for some other reason. At one time,

we had the idea of seeking out particular examples of unsuccessful research and exploratory development, but this method was never supported. Then it was believed that we could get data about some other population of research and exploratory development activities different from a population selected for utilization. It was assumed that we and the members of the steering group would have ready access to bodies of information about projects in general, average conditions, and so forth, which they could quickly turn into a composite picture of a control population. However, the very thought of gathering together such a body of information and stigmatizing it as characteristic of "other" or "unsuccessful" research and exploratory development met so much resistance that all such attempts were abandoned very early in the project. Informally, it was made very clear to us by a number of people that it would be inexpedient to pursue this line at the present time. As a consequence, all our data concerns utilized research and exploratory development only.

The methods of research and exploratory development management and the environmental patterns found in our study seem to be the ones which are in common use today. Without a control population, it is difficult to tell whether their distribution is enough different from that of a random selection to be significant. But in any case, nothing was uncovered which struck the investigators as exotic or highly unusual. Contrasts between research and exploratory development procurement methods which are successful and those which are not are therefore not warranted. Many examples show environment patterns differing from the ordinary traditions, rules, and regulations. If one assumes, as we have, that these differences are causally related to success, then inferences can be drawn about general environmental patterns conducive to the execution and utilization of good research and exploratory development. Extrapolation from these inferences suggests that some patterns not commonly used today by the Defense Department should be more effective than many of the patterns which are in use. But the inference that these patterns are more desirable cannot be supported with examples.

3. Suggestions for Improvement

The most important weaknesses of this study cannot be corrected by changing the methodology, for they concern the establishment of objectives and communication and implementation of the results. Several of the problems mentioned above are concerned with ambiguities or uncertainties in the methodology which probably can be corrected more easily when the objectives of such a study are better defined and when a way of using the results is more explicitly understood. The one gross deficiency in the methodology which should be corrected is the lack of a way to look at failure. Any future study carried on by these methods should be provided with means for studying unutilized and unsuccessful research and exploratory development as well as the successful and the utilized.

C. FURTHER SUBSTANTIATION OF RESULTS OF DOUBTFUL VALIDITY

The distinction between the way goals and objectives figure in the initiation of exploratory development and the way they figure in the initiation of research could be examined in more detail.

For this to be successful, a shift in emphasis would be required in order to uncover more RXD Events having to do with research. At the present time, the Defense Department spends far more money on exploratory development than on research, and can look forward to exercising far more control over it. The wisdom of devoting special effort to illuminating this specific point about research management may therefore be questioned.

A further analysis could be made of the way members of a research or exploratory group use communications with a sponsoring agency when the sponsoring agency will not support a consensus-collaboration relationship. This could probably be done better by behavioral scientists than by scientists and engineers chosen for their understanding of the technical content of the research and exploratory development in question.

The various ways in which the Defense Department supports or resists innovation, with particular reference to the way in which it adopts new technology in weapon systems, should be studied. Insofar as this resistance or support is anticipated, it affects the way in which the research and exploratory development is done. Some of these effects have been described in the present study. However, after the exploratory work itself is complete, its success remains uncertain, and depends on how successfully it can be exploited. Connected with this is the question of how adaptively functioning suborganizations can be incorporated in a larger organization which fundamentally follows the traditional authorization pattern, in such a way that the authorization organization is not seriously disturbed, but yet the innovative consequences desired from the adaptive subunits are achieved.

D. INTERESTING PROBLEMS BEYOND THE SCOPE OF THIS STUDY

A number of conclusions and observations concern matters which were never expected to be within the scope of this study, but which merit further study on the basis of their own value and intrinsic interest.

Some of the institutions we saw had educational support programs; subjectively, these same institutions appeared unusually productive. Is there any relation between productivity and the educational support program? It may be that such a program contributes directly to the professional competence of the staff, that it contributes indirectly by making the institution more attractive, or that it is related to productivity only as being a normal consequence of a particular type of management policy.

The growth and aging cycle of research and development institutions and groups is an interesting open problem. In most of these, productivity does not reach equilibrium and remain there, but fluctuates even when the internal organization and external support appear stable. It has been suggested that a new laboratory may function best on its first mission, because at that period in its development it operates according to an adaptive system. As it grows older its actual operation may fall into the more common and traditional authoritarian pattern. If this turns out to be a common course, another problem is to learn how to identify this, to offset it, or, as a last resort, wipe out the establishment when it is no longer able to serve its function.

Some recent work in behavioral sciences suggests that creative and innovative people have traits of behavior and personality which will put them at odds with many organizations and social institutions. We saw very few examples associated with our RXD Events. Does such a personal type exist, do such people conceal their natural tendencies, are they excluded from organized research and development activities systematically, or do they actually find themselves at home in organizations where research and exploratory development is the principal activity?

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V. A REVIEW OF THE COURSE OF THIS STUDY

A. FORMULATION OF OBJECTIVES

Section I contains a brief statement of the problem, and Appendix A contains the whole statement of Scope of Work, Statement of the Problem, and Method of Approach, as found in the Work Statement of the contract.

During the second week of the study an extended meeting was held by the steering group and the Arthur D. Little staff members. At that time, the use and purposes of the study were further described:

> "This study has two important aspects. One is to gather particular information about certain development projects and the research and exploratory development which provided the technical foundation for subsequent development, and to organize this information to show the relationships between management environment and subsequent utilization of R & D results. The other is to pioneer in methods of gathering and organizing such information."

The methodology was based on historical analysis of the research and exploratory development origins of a number of weapon systems. Five tasks were defined as comprising the job:

1. For each weapon system, identifying the technological advances utilized without which the system would not be operational ("technical items" or "key ideas" -- it was difficult for the conferees to agree upon a short designation).

2. Making a detailed exploration and description of the management environment surrounding these advances.

3. Forming hypotheses concerning the relation between management environment and technological advances.

4. Making recommendations concerning future DDR & E policy.

5. Reading literature and state-of-the-art studies as sources for background material ("intellectual background").

It was originally hoped that the Defense Department would appoint a group of about five people as full-time participants in this activity to carry on cooperative and parallel efforts. This proved not to be feasible, but two members of the Department of Defense did commit themselves to full-time activity on this study for nearly its whole duration. A number of others rounded out a steering group of five individuals, all making substantial contributions in spite of their limited commitment of time to the job.

Conclusions and recommendations are not required by the work statement, which asks only for formulation of hypotheses about the relationship of environmental factors to degree of utilization, and satisfactory agreement between observations and hypotheses. Nonetheless, it has been possible to draw some conclusions and make some recommendations. The work statement does, however, express the hope that "after a few instances are studied, there will be a general agreement about what constitutes a key idea for the purpose of this study." This hope has not been realized. Even in the last month of the study, agreement on a valid discrete unit of research or exploratory development for the purposes of this study is far from unanimous.

B. HISTORICAL ANALYSES OF WEAPONS SYSTEMS

Our historical analyses of weapons systems had four objectives. The first objective was to identify particular examples of research and exploratory development (later formalized as RXD Events). The second was to establish the utilization of this research and exploratory development in a recent weapon system, and to show how its use came about. The third was to show how the consequences of the research or exploratory development affected the configuration or the performance of the weapon system. The fourth was to show the relation of this research and exploratory development to the science and technology of its day.

The identification of particular examples of research and exploratory development in RXD Events was necessary as a starting point for a later phase, the study of RXD Event Environments. In the past it was more common to take a group, a laboratory, or an institution as a basic environment, and examine its productivity in terms of all of the research and development activities carried out there. When the environment of a single discrete research or exploratory development activity is sought, it is necessary to specify exactly what this activity is. Section V-C discusses in greater detail some of the problems in identifying RXD Events.

It was necessary to establish that the RXD Event had consequences actually used in recent weapon systems, because the feature distinguishing these RXD Events from other research and exploratory development activity, and making them an interesting example for environment research, is precisely that their consequences were used. When the study was undertaken, we anticipated that we might have difficulty in determining whether a particular research or exploratory development activity was utilized. In fact, this has not been the case: it has always been clear to us and to others if a particular RXD Event was utilized.

Showing how an RXD Event contributed to the value of a weapon system has proved to be much more difficult than showing that it was utilized. In some instances, one element or subsystem replaced another with substantially no change in the rest of the weapon system, and a straightforward comparison was possible; but such cases characteristically showed rather small improvements. On the other hand, when a big technological novelty was introduced, it normally required an alteration of the system configuration and the introduction of a number of other technological innovations before its full value could be exploited. It was then hard to decide how to distribute the credit for improvement among the various innovations.

The change in historical perspective also contributed to the difficulty of showing how a particular technological innovation affected the value of a weapon system. A technological innovation does not spring into being full grown, and its value is often not immediately appreciated. In many cases the value of a technological innovation is enhanced by later development and by an understanding of how to exploit it. Its value is likely to grow on a typical "learning curve." If a technological innovation overtakes its predecessor after the old technology is mature, the improvement in value may approximate a step, as in Figure V-1A. If the two technologies are both growing, the new is likely to replace the old shortly after performance or value estimates cross. In this case (illustrated in Figure V-1B), the contemporary estimate of performance improvement is small compared to a retrospective evaluation of the merits of the respective technologies, and a historical search for the "big step" improvement in performance is frustrated. In some instances the initial jump is nullified or even inverted, because incompatibilities arising from introduction of a technical innovation are not foreseen and compensated for early enough. We found a number of instances where technological innovations introduced in one model of a weapon system were removed in subsequent models. Presumably they were used on the basis of an estimate, made in good faith, that they would be more satisfactory than the alternatives that they displaced. Evidently a more mature evaluation showed that this was not true.

In the end, it was decided that the fact that an innovation had been used in a weapon system was more significant than an estimate of the value of the contribution. Where any estimate of value could be made, we attempted to do so, but the decision whether or not to include an RXD Event in our population hinged on whether it was used rather than on whether it contributed more than a certain amount of value.

The relationship of an RXD Event to the science and technology of its day shows many of the factors which influence program planning and program management. It shows whether the RXD Event was unique, or whether there were other R & D activities which might have led to equivalent results. It shows whether the activity was specific to the application we saw, or whether it was fallout from R & D aimed at other goals. It shows whether the application we saw was the only application, or whether it had other immediate significant consequences. These factors are much easier to judge retrospectively, but necessarily form a large part of what the contemporary program planner bases his judgment on.

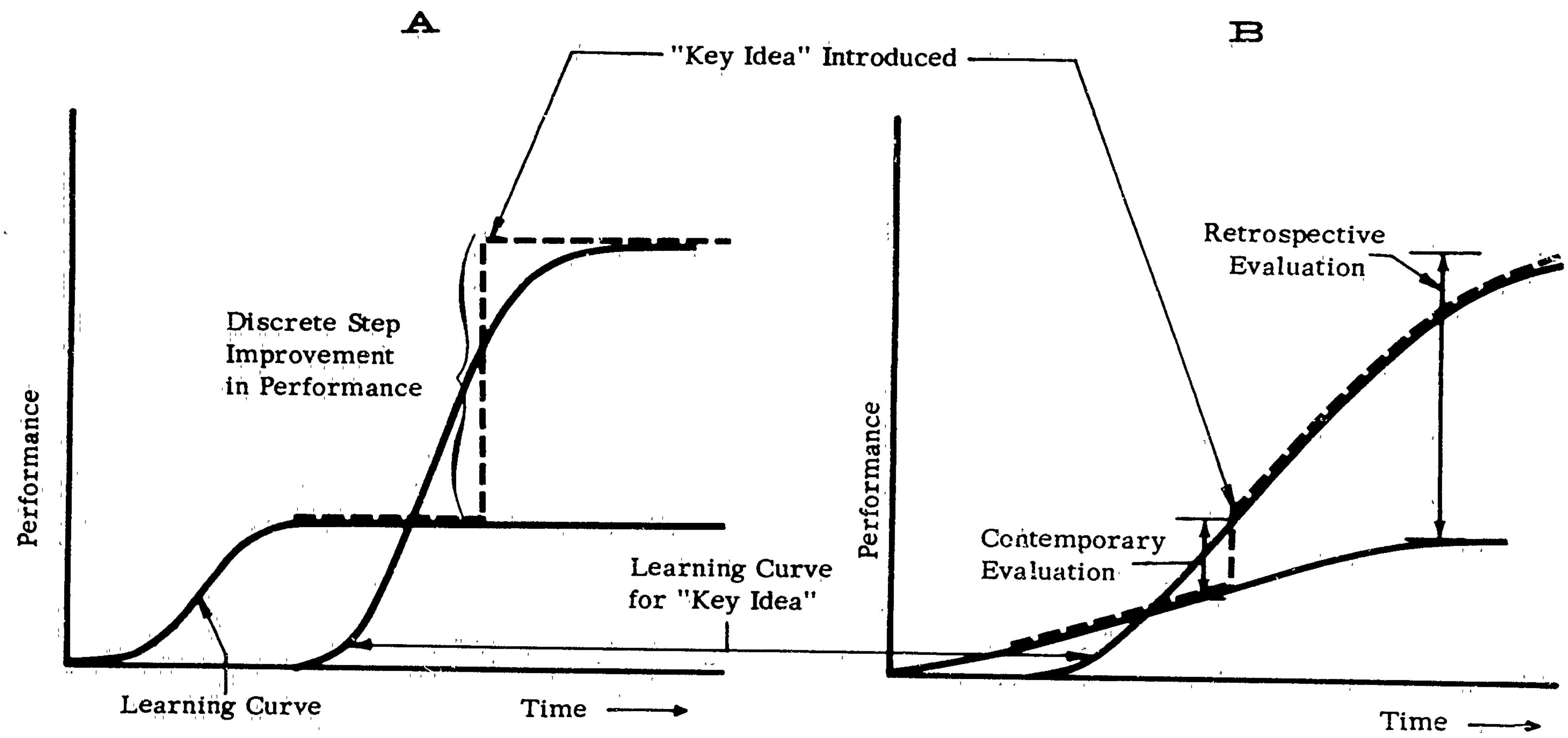

FIGURE V-1 IMPROVEMENT IN SYSTEM PERFORMANCE AS A FUNCTION OF TIME WHEN A NEW "KEY IDEA" IS INTRODUCED

We studied the following six weapon systems*:

Mark 46-0 Acoustic Homing Torpedo
XM-102 105mm Howitzer
AGM 28 Hound Dog Air-to-Ground Missile
Polaris A-1 Missile
Minuteman Missile
Sergeant Missile

The first three of these systems were studied relatively independently from one another. The last three are all large inertially guided solid fuel missiles, and since it was anticipated that the fundamental technology underlying them would overlap considerably, they were studied jointly by a single team. In the end, three areas of technology were identified in which the background and technological history of these three weapon systems overlapped so much that the studies were merged completely. These were the solid fuel propulsion subsystems, the inertial guidance and navigation subsystems, and the electronics, insofar as it depended on semiconductor devices. These three areas of technology were studied somewhat independently of the particular weapon systems, and the results were later correlated with known features and applications in the weapon systems under study.

A brief review of the technology of these six weapon systems and three areas of technology is contained in Section III. The charts in that section show the RXD Events which were identified, and illustrate their relation to weapon system development.

The principal method of investigation was by direct personal contact with people responsible for system and subsystem performance and development. We invited these people to discuss freely the early stages of the technical development of the systems, subsystems, components, devices, etc., in which they had a hand. We urged them to identify turning points, breakthroughs, significant problems, and other aspects of the development cycle which suggested modification of a train of thought or abandonment of a preceding idea. When such a turning point was detected, we attempted to identify sources of ideas and stimulation, and repeated the whole process with personnel involved in the earlier stage of evolution. We also studies historic evaluations of the systems and their development, and contemporary accounts of the research and development activity, and formed our own opinion of areas in which significant technical innovation had been introduced.

*In addition, the DDR&E steering group made a brief but intensive study of the Bullpup missile.

In studying the early development of semiconductor devices, including particularly the transistor, we deviated from this program. We knew that the early research and exploratory development work either was done at the Bell Telephone Laboratories or was so thoroughly intertwined with the work done there that a thorough examination of the work done at BTL would immediately reveal most of the information. Wherever transistors and other recently developed semiconductor devices are used, they rely at least in part on the research and exploratory development at or associated with the Bell Telephone Laboratories. Therefore, we studied this activity independently, and made no further attempt to justify the statement that the consequences of this research and exploratory development were utilized. It is noteworthy that this study of research and exploratory development in semiconductor devices very quickly yielded a much higher proportion of research activity than any of the other studies.

Almost all of the members of Arthur D. Little's staff who worked on this job had experience in actually carrying out research and exploratory development, and the majority had first-hand experience in the supervision of research and exploratory development. At the express request of the representatives of DDR & E, almost all were engineers and physical scientists. When the job was initially discussed, a great deal of skepticism was expressed about the literature of the social sciences and about trends in modern management theory, and it was expressly emphasized that the study should be carried out by people who had practical experience in research and research management, who were fully capable of gaining an understanding of the technical content of the research and exploratory development activities they were investigating. Although this condition was never entered into the work statement, it is implicit in the personnel qualifications carried as an attachment. In the end, one consultant with a background in social science and specialization in the organization of technical institutions was retained, but the central roles in the study were all carried out by men with backgrounds in physical science and engineering.

C. IDENTIFICATION OF RXD EVENTS

1. What are Research and Exploratory Development?

In attempting to define what is meant by an RXD Event, we have come across four different, relevant definitions of research and exploratory development. These are:

> the present Defense Department's definitions of research and of exploratory development;
>
> a description of an idealization of what every R&D man or group leader calls a project, an activity with circumscribed objectives, carried on as research or exploratory development, in many cases with funding from the Department of Defense;
>
> an idealization pragmatically arrived at for the purposes of this study, comprising a description or an idealization of those things, whatever they are, whose environments is is our intention to study; and
>
> an idealization for the future describing the purposeful scientific creation and technological innovation whose consequences may influence warfare, especially those which may lead to cheaper and more effective weapon systems and other materiel, in which we think the Department of Defense ought to be interested whether or not its description agrees with any of the above.

What the terms research and exploratory development mean to any man depend on his past experience and on his point of view. There is a particularly big difference between the point of view of the man in the laboratory who is actually carrying out research and exploratory development and that of the sponsor who is buying research and exploratory development. All definitions of research and exploratory development are colored with considerations of motive, intentions, and expectations. The reasons which a corporate manager or a military program sponsor has for supporting work on a particular research project may be very different from the reasons that the principal investigator has for carrying it out.

So far as this report is concerned with individual RXD Events and their environments, we have usually adopted a point of view close to that of the man in

the laboratory actually doing his exploratory work. From time to time this revealed a glaring inconsistency between his point of view and that of non-participating managers and sponsors; an attempt was made to identify these inconsistencies. Where we failed to do so, we ask the reader to consider the possibility of different points of view before concluding that an error has been made.

The present definitions of research and exploratory development used by the Defense Department are as follows:

Research (6.1) - Includes all effort directed toward increased knowledge of natural phenomena and environment and efforts directed toward the solution of problems in the physical, behavioral and social sciences that have no clear direct military application. It would, thus, by definition, include all basic research and in addition, that applied research directed toward the expansion of knowledge in various scientific areas. It does not include efforts directed to prove the feasibility of solutions of problems of immediate military importance or time-oriented investigations and developments. The research elements are further characterized by using level of effort as the principal program control.

Exploratory Development (6.2) - Includes all effort directed toward the solution of specific military problems, short of major development projects. This type of effort may vary from fairly fundamental applied research to quite sophisticated breadboard hardware, study, programming, and planning effort. The dominant characteristic of this category of effort is that it be pointed toward specific military problem areas with a view toward developing and evaluating the feasibility and practicability of proposed solutions and determining their parameters. Program control of the exploratory development element will normally be exercised by general level of effort.

Further stages in the RDT&E program are categorized as follows:

Advanced Developments (6.3) - Includes all projects which have moved into the development of hardware for experimental or operational test. It is characterized by line item projects and program control is exercised on a project basis. A further descriptive characteristic lies in the design of such items being directed toward hardware for test or experimentation as opposed to items designed and engineered for eventual Service use. Examples are VTOL Aircraft, ARTEMIS, Experimental Hydrofoil, X-15, and Aerospace Plane Components.

Engineering Developments (6.4) - Includes those development programs being engineered for Service use but which have not yet been approved for procurement or operation. For example, MAULER, TYPHON, B-70. This area is characterized by major line item projects and program control will be exercised by review of individual projects.

Management and Support (6.5) - Includes research and development effort directed toward support of installations or operations required for general research and development use. Included would be test ranges, military construction, maintenance support of laboratories, operations, and maintenance of test aircraft and ships. Costs of laboratory personnel, either in-house or contract-operated, would be assigned to appropriate projects or as a line item in the research, exploratory development, or advanced development program areas, as appropriate. Military construction costs directly related to a major development program will be included in the appropriate element.

Operational System Developments (6.7) - Includes research and development effort directed toward development, engineering and test of systems, support programs, vehicles and weapons that have been approved for production and Service employment. This area is included for convenience in considering all RDT&E costs of weapons systems elements in other programs. Program control will thus be exercised by review of the individual research and development effort in each weapon system element.

The definitions of research and of exploratory development (and of Advanced Development also), are based on two criteria only: the purpose for which the work is to be exploited, and the character of the funding to support and control it. Nothing is said about the nature of the work. These definitions are straightforward for the sponsor of research and exploratory development, who is presumably in a position to decide why and how he wants to fund a program, but they are largely irrelevant in any attempt to learn from work actually done or from the people who actually did it, which category the work falls into. We know from a number of examples that the goals and objectives of the people actually executing the work may differ from the goals and objectives of their sponsors. We know also that they are usually ignorant of and often indifferent to the particulars of funding, and sometimes even to the general source of funds. We conclude, therefore, that the existing definitions are useful in program planning and funding control by the sponsors of research and exploratory development, but are not useful as categories for describing actual instances of exploratory and innovative activity in terms of what was done, how it was accomplished, who did it and why.

A more realistic definition is an idealization of a unit of work commonly recognized by research workers and managers as a project. This is likely to be an activity carried on by a small number of people, in close contact with each other, with unity of content and purpose, managed by a single line supervisor (if there is any formal management structure at all). A study of the RXD Event Description format (Appendix B) shows that such a definition was chosen fairly early as a foundation for our RXD Event identifications. At that time it it was assumed that research, exploratory development, and all other innovative

activity naturally fell into such discrete units, and that our problem was simply to locate these units and identify them. Experience in attempting to do this suggests, on the contrary, that the RXD Event Description, or any other idealization of a discrete research or exploratory development activity, is a man-made concept, which may or may not correspond to the actual way in which technical innovative activity is carried out. Such a definition may, of course, be agreed upon as a basis for further study, to eliminate the tensions resulting from certain kinds of uncertainty and ambiguity. However, it should not be allowed to become the basis for an assumption that the concept agreed upon is a basic building block in the real world, and that actual circumstances will always fit the description.

This study is concerned with how research and exploratory development are administered by the Department of Defense. In this context, the two definitions mentioned above appear adequate. However, from a more general point of view, this study is concerned with how technological innovations are introduced into weapon systems development. To understand this, it is important to study the origins of technological innovations, whether or not they conform to any other idea of research and exploratory development. A particular example can be found in the activity involved in the conception of a bare-missile, air-ejected submarine launching system, which was ultimately used in the Polaris system. This work was exploratory in character, involved the imaginative use of new ideas, and resulted in innovation which was very important to the operational usefulness of the Polaris missile; yet it has defied all attempts to describe it as an RXD Event. Nonetheless, it has been agreed that this activity resulted in significant technological advances and that the environment in which it took place is one which should be investigated.

The research and exploratory development activities chosen in this study for environmental research are probably not fully representative of the types of constructive innovative activity which the Defense Department's research and exploratory development program should encourage. We can make a non-exclusive definition of what we think the Department of Defense Research & Engineering ought to be interested in: purposeful creative and innovative activity whose consequences may influence warfare. This can be restricted to scientific and technological activity, and further to that particular kind of activity which may lead to cheaper and more effective weapon systems and other military materiel. Such a characterization certainly overlaps with the other three definitions, but it is not co-extensive with any, nor does it yield immediate operational criteria enabling us to decide whether a particular activity really belongs to the category or not.

2. Conflicts Aroused in Reconciling Definitions of Research and Exploratory Development

A number of inconsistencies among definitions of research and exploratory development could be resolved by adopting a minor variation of the definition which is now official. The variation is that it would be required to make the official definition agree with descriptions of present projects and program elements. Such a change would resolve rather than augment some of the present uncertainties. It would also satisfy a common human desire to choose a definition once and for all and would provide a rational basis for a library of consistent data.

If we assume that exploratory development and research exist objectively in the real world apart from the process we use to define them, such a course is entirely rational. We believe, however, that these terms are in part the product of human inventiveness and that it is unwise to settle upon a rigid definition so soon. Hayakawa has observed in connection with a certain class of problems:

> "Most intellectual problems are, ultimately, problems of classification and nomenclature...The usual way in which such questions are settled is by appeals to etymological dictionaries to discover the 'real meanings' of...words... The decision finally rests, however, not upon appeals to past authority, but upon what society wants...Society, in short, regards as 'true' those systems of classification that produce the desired results." (5)

We believe there is a great deal more to be said on how the results of the present study are to be used, and we also believe that the ease with which results of studies like this can be used depends in part on how definitions such as those of research or exploratory development are framed. We recommend, therefore, that research and exploratory development be defined for the time being as the work represented by the RXD Events labeled "R" and "XD" respectively, and by other work which later investigators see fit to put into the same categories. It is to be hoped that conscientious investigators will not frivolously classify data into categories, and that when more data are accumulated really meaningful distinctions between these categories will be made clear. It seems obvious to us that differences based on funding sources and the short term expectations of sponsoring agencies are not the most basic differences between research and exploratory development, and are not a suitable basis for dividing our population into categories for the study of environments.

3. RXD Event Description

The actual working definition of an RXD Event is a compromise between an idealization of the commonly felt concept of a research or exploratory development project, and a description of the particular items of exploratory activity whose environments we thought it important to study. The principal features of the RXD Event Description format and the instructions provided to guide fieldworkers in filling it in are given in Appendix B.

We conceive of an RXD Event as a period of technical activity with a well defined outcome. One of its attributes is that it involves some creative or innovative act; another is that it produces an irrevocable or irreversible change in the state of knowledge, in the understanding of what is feasible or how something can be done. This outcome must be such that the RXD Event influenced the development of the weapon system. The outcome may be a progress report, a proposal, a journal article, a patent disclosure, or some other document which summarizes the information generated in the RXD Event; it may also be a verbal presentation, a successful execution of a field test, a consensus in a committee meeting, or some other action not ordinarily conceived of as information-bearing or information-transmitting.

The outstanding quality of the outcome is that it is the dividing point between the state of knowledge before the RXD Event was completed, and the state of knowledge after the RXD Event was completed. An extreme test is whether the knowledge contained or derived from the RXD Event would be preserved and propagated from that point onward without any further contribution from its protagonists.

A clear understanding of the outcome leads directly to a description of a second datum, the technical activity. This describes the work which was actually done, such as computation, environmental measurement, systematic testing or whatever the actual participants in the RXD Event would have answered if asked during the course of a day's work, "What are you doing?"

A third datum is the origins of the RXD Event. This is construed broadly to include anything from an accident of fate to a universally recognized human crisis: that which motivates or triggers the purposeful technical activity leading to the outcome.

These three data are reported in Section 5a of the RXD Event Description form, Origin, Technical Activity, and Outcome. They are preceded by a very brief statement of the technical activity, which hints at the origin and the outcome. This brief statement is available as a short description of the RXD Event in circumstances where the title is insufficient.

The remaining items in the RXD Event Description form are then fairly well defined by the origin, technical activity and outcome of the RXD Event and the particular questions and instructions accompanying the description form. Appendix B also includes a copy of RXD Event Description No. 20, Development of Pyrolytic Graphite, as an illustrative example.

D. RXD EVENT ENVIRONMENTS

1. Early Ideas About Environmental Factors

Even after the boundaries of an RXD Event have been carefully delineated, the circumstances and influences comprising its background are almost limitless. Since the detail in the environment descriptions must be limited, it is desirable to have some rational criterion for choosing the detail to be retained.

The first place to look for a rational criterion is the primary purpose of the study as a whole. All statements of this underlying purpose, including the early statement by the Defense Science Board and the Scope of Work, Statement of the Problem, and Method of Approach from the governing contract (Appendix A) imply an intention on the part of the Department of Defense to consider new research and exploratory development procurement policies and procedures in order to improve its use of research and exploratory development resources. Even such a general statement is sufficient to limit the range of environmental factors which can be considered relevant.

First, any information on which decisions are to be based must be available before the deadline for decision-making has passed. Therefore we can rule out factors which are intrinsically observable only after the work has been completed. The environmental factors of interest are those which are easily observable before or during the execution of a program.

Second, these factors must be related to the value, cost, degree of utilization, or some other index of merit and effectiveness of the research and exploratory development. It is advantageous if a causal relation can be established between an environmental factor and some index of RXD effectiveness, but it is still of interest if only a correlation or an association can be established. Factors unrelated to RXD effectiveness are probably of interest only if identifying them corrects an error or resolves a previously existing uncertainty about research and exploratory development management practice.

Third, these factors should be influenceable by the Department of Defense. This includes factors such as the type of funding, which can be directly controlled, and those, such as climate, which may be selected, if not controlled.

Finally, we examined redundant or supporting data by asking ourselves whether the value of the data was in due proportion to the labor required to collect them.

Our initial list of environmental factors was that contained in the work statement: circumstances of initiating, planning, contracting, financially supporting, organizing, staffing, controlling, evaluating, and utilizing the results of each key idea. This list was augmented in a number of ways, but it became obvious that we could form no integrated picture of an environment out of the kind of fragmentary information derived from examining such factors one at a time.

To draw up a list of environment factors which would coalesce into a complete picture, it seemed desirable to start out with some idea of what the picture should look like. For this reason we undertook to describe models for the environment of research and exploratory development. It was anticipated that the model hypothesized would provide the broad outline, and that the questions and answers necessary to fill in the details on the model for any particular example would themselves constitute the list of environment factors to be considered.

Particular attention was paid to four classes of environment models, those which depend respectively on: structure, function, interrelation among organizational entities, and motivation and attitudes.

At this point in our study, it seemed that a study of organizational structure was an entirely appropriate starting point for environment research. A program of investigation was drawn up to look at organizational factors. At about the same time, we decided to make one pilot study of environment with a very high degree of detail. We had no way of deciding whether a given list of environmental factors was insufficient or excessively detailed, or whether it covered the wrong ground, and the only way to find out seemed to be to carry on one study covering environmental factors in considerable detail in all directions, and to try to learn afterward which were important and which were not. This study, which is briefly reviewed in the next section, proved to be a turning point in all of our thinking about environmental factors. In the end it led us to abandon the first two models of organization, and to devote nearly all of our effort to the other two.

2. Lessons from a Study of the Environment in which H-6 High Explosive was Developed

The pilot study of research and exploratory development environment was a study of the environment at the Naval Ordnance Laboratories in the Bureau of Ordnance, which resulted in the formulation of the chemical high explosive H-6 used in the Mark 46-0 Acoustic Homing Torpedo.

H-6 was the first high explosive mixture belonging to this family to be used in an underwater weapon. Until shortly before the Mark 46 torpedo went into development, there had been considerable uncertainty about which high explosive parameter or combination of parameters should be maximized in order to make a short range underwater weapon most effective. At about this time, it was finally determined that total shock energy, rather than total explosion energy or bubble energy, or peak pressure, was the parameter to maximize; and within its family of three-component mixtures, H-6 had the proportions leading to maximum shock energy.

During World War II there was considerable activity in the development of high explosives, much of it sponsored by the National Defense Research Committee at the Woods Hole Oceanographic Institution and at Bruceton, Pennsylvania. The National Defense Research Committee activity closed down at the end of the war, at just about the same time that the Naval Ordnance Laboratory was moving into its new quarters at White Oak and was expanding its staff. Commander Stephen Brunauer, Chief Technical Administrator for Explosives Research and Development at the Bureau of Ordnance, saw to it that the new organization of NOL included an Explosives Research Department. He used his personal influence and professional contacts to help in staffing the new laboratory with people whom he knew to be able, and who had been carrying on research and development in high explosives during the war.

During the same period, Dr. Brunauer and his colleagues undertook to plan and provide for many interesting pieces of work in high explosives development. In particular, they canvassed government laboratories, industrial laboratories, and universities for ideas about potential high explosive mixtures and compounds. One formal result of their efforts was a Naval Ordnance report[6] which makes a number of specific suggestions for research in explosives having higher energy than those used during World War II. Among the families of explosives suggested is the ternary family containing RDX, TNT, and aluminum, to which H-6 belongs.

In addition to this in-house work, the Explosives Research and Development Office also funded a large number of exploratory programs with a number of contractors. Many of these provided continued funding of, or followed leads arising from, NDRC-sponsored work.

Finally, the members of this office maintained a position of close personal and professional contact with the members of the new Explosives Research Department at NOL, and participated in the launching of their initial research programs and in the continued planning and support of their activities on behalf of the Navy.

One of the programs undertaken at NOL was a systematic evaluation of a range of castable mixtures of RDX, TNT, and aluminum to determine the optimum explosive mixture for air-blast. A wide range of laboratory and field tests was made on 23 representative mixtures of this ternary family. This particular study concluded that the mixture later called the H-6 was the most effective among castable mixtures for weapons intended to be exploded in free air.

A similar program was being carried on at just about the same time, with the aim of preparing an underwater explosive with performance superior to those commonly used in underwater weapons during World War II. The same ternary family was studied, and a number of tests were carried out resulting in tables and graphs of shock wave energy, bubble energy, peak pressure, and other parameters important in the dynamics of explosion damage. At this time, no identification of the "best" mixture for use in an underwater weapon could be determined, because there was no unambiguous criterion of excellence.

Work was started at about the same time at NOL and at the Underwater Explosives Research Division of the David Taylor Model Basin near Norfolk, Virginia, to determine the contribution of various explosion parameters to underwater damage phenomena. No definitive results came from this work for a number of years, but around 1957 it was finally determined that for a weapon intended to explode at short range, maximization of underwater shock wave energy is more advantageous than any of the other underwater explosion parameters used as indices of effectiveness. It was then easy to go back to the work on underwater explosion parameters at NOL and determine that the mixtures having highest shock energy were those containing 20 to 25% aluminum. By this time the H-6 explosive, with 22% aluminum, had already been approved for service use in an air-blast weapon, which made it unnecessary to submit a new formulation for the long, tedious, and expensive procedure required to gain approval for service use. The H-6 mixture, exactly as formulated for air-blast use, was adopted for use in the underwater weapon.

Further details of this group of interconnecting activities is given in RXD Event Description Nos. 93, 94, and 95.

In August 1964, we approached the Naval Ordnance Laboratory and the Bureau of Ordnance and a number of former employees of these establishments for an extensive series of personal interviews aimed at understanding the environment in which the particular development of the H-6 high explosive took place. We guided ourselves by the following three questions:

Why did this RXD Event take place?
Why did this RXD Event take place where it did?
Why did this RXD Event take place when it did?

We came prepared to consider a large number of variables and environment models, to review progress reports and funding documents, to study work statements and technical reports, to examine organization charts and learn about personnel policies, and in general to take any amount of trouble necessary to satisfy ourselves that any particular environmental factor did or did not bear significantly on the conduct of this particular activity.

In addition to talking to people, we reconstructed the explicit and complete table of organization of the whole department for two points of time during the period of interest; reconstructed the total funding history of the program as actually carried out; reviewed all of the technical reports on file in the library bearing directly on this technical activity; reviewed a number of informal written documents still in the possession of their authors; and examined the formal and informal policy governing funding, staffing, reporting, procurement, acquisition of equipment and facilities, professional relations with the scientific and educational communities, and many other factors.

In the end, however, after sifting the evidence as we were able to gather it, we found only six factors or groups of factors which appeared to us significant. These are:

1. The members of the professional staff had a complete general understanding of the goals and objectives of the high explosives research program, and were personally committed to them.

2. Among the working groups, planning, control, and discipline were by general agreement based on a collective judgment of task needs and urgency, backed up by (but not anticipated by) formal administrative action where necessary.

3. The professional staff members at NOL had close personal and professional relations with their sponsors, the Explosives Research and Development Office in the Bureau of Ordnance.

4. The members of the Explosives Research and Development Office in the Bureau of Ordnance actively sought the collaboration of professional staff members at NOL in a variety of matters, including the planning and evaluation of NOL's own program.

5. The head of the Explosives Research and Development Office at the Bureau of Ordnance, Commander Stephen Brunauer, is credited with great motivation, technical understanding, and persuasiveness, and with having used his personal resources in planning a high explosives program, in staffing the initial NOL activity, in setting up the initial organization of high explosives

work at NOL, in participating in and guiding the technical program in high explosives, and in seeking financial support for the program both inside and outside of the Navy.

6. The NDRC activity in high explosives was being shut down at just the time that the NOL activity was being built up; this made available lines of research and development which had not been fully exploited, and experienced professionals who were well motivated to complete the exploration of unfinished areas of work.

While uncovering this group of six findings we were unable to convince ourselves that less personal and more objective factors were as significant in the successful execution and utilization of this RXD. This caused us to revise our opinion of what constitutes a good description of an environment, and to go to the literature of the case studies of research and development environments for help in interpreting our observations.

3. Lessons from the Literature of Management Theory and Sociology

a. Introduction: Authoritarian and Adaptive Environments, Coercion-Compromise and Consensus-Collaboration Relations

The results of our literature search are described in the paragraphs below. We limited ourselves for the most part to studies containing field data or based on field investigations of environments where research and exploratory development were being done.

The most significant finding for the purpose of this study is the identification of two polar classes of management environment, which we have called authoritarian and adaptive. A number of authors have talked about similar concepts, using a variety of terms. Table V-1 is a brief concordance.

In this report we used the pair "authoritarian" and "adaptive" when talking about local organizational environments in general and the terms "coercion-compromise" and "consensus-collaboration" when emphasizing particularly the relations between pairs of individuals or groups.

TABLE V-1

TERMS RELATED TO AUTHORITARIAN AND ADAPTIVE

Source		
Present Report	Authoritarian	Adaptive
Present Report	Coercion-Compromise	Consensus-Collaboration
Burns and Stalker	Mechanistic	Organic
Sheldon A. Davis	Authoritarian	Dynamic
Herbert Shepard	Coercion-Compromise	Consensus-Collaboration
Simon Marcson	Executive Authority	Colleague Authority
Alvin Gouldner	Rational Model	Natural System Model
Douglas McGregor	Theory X	Theory Y

b. Hower and Orth, "Managers and Scientists"(7)

A search for publications containing field data about particular localized environments in which research and exploratory development is done, at once brought to light a study by Hower and Orth. This book presents a number of cases involving human problems in industrial research organizations, particularly problems in the relations between scientists engaged in R & D activities, on the one hand, and management personnel on the other. The focus of the study was upon matters of status, communication, motivation, morale, and manager development.

The book presents a large amount of data, but offers no straightforward conclusions. The authors, however, discovered and described two cultures during their studies, management culture and scientific culture, which are differentiated by their value systems. The authors are careful to assert that value systems alone are not sufficient to bring a full understanding of human behavior. However, they were able to use them to explain some of the things which they saw and heard in the environments which they studied, and they confirmed our observation that motives and attitudes were important factors to consider in describing and evaluating a research or exploratory development environment.

c. Burns and Stalker, "The Management of Innovation"[8]

Burns and Stalker based their conclusions on three sets of studies of technical innovation in an industrial environment.

The first study, originally directed at another purpose, discussed a growing and commercially prosperous rayon mill with a functioning hierarchic control system. The functions of each manager and worker were clearly specified; they were expected to follow, and did follow, the instructions which issued in a steady flow from the general manager and through the hierarchy. The system worked smoothly and economically, with the exception that the research and development laboratory failed completely in its formal responsibility for solving problems, curing faults, improving existing processes and products, and introducing new products or methods.

A succeeding study was concerned with an engineering company with very large development interests. Here, because of the deliberate policy of the head of the company, the ranks and functions of the hierarchy of management were ill defined. The president believed that the first requirement of the management system was that it should make the fullest use of the capacities of its members; any man's job should, therefore, be defined as little as possible, to allow it to expand or contract in accordance with his special abilities. Throughout the organization there was a sense of insecurity, and the employees dissipated much energy in internal politics and other actions clearly dissociated with the concern's tasks. Yet the firm was a commercial success, arousing the suspicion that those organizational consequences which appeared to be defects were inevitably associated with organization for industrial change.

The next study was of a group of firms in Scotland which were attempting a systematic and orderly transition from their former line of work into electronics development. Here the authors identified two divergent systems of management practice, which they call the <u>mechanistic</u> and the <u>organic</u> form. A mechanistic management system is appropriate to stable conditions, while the organic form is appropriate to changing conditions, which constantly give rise to fresh problems. Such problems require action, which cannot be broken down or distributed automatically according to the functional roles of the hierarchy structure. The outstanding characteristics of these two contrasted forms are found in Table V-2.

The investigators later had an opportunity to study a group of eight English firms, concentrating on the management difficulties peculiar to firms engaged in rapid technical progress, and the particular problem of getting laboratory groups, on the one hand (research-development-design), to work effectively with production and sales groups, on the other.

TABLE V-2

ORGANIC AND MECHANISTIC MANAGEMENT SYSTEMS

Tom Burns, and G. M. Stalker, The Management of Innovation, pp. 119-122

Mechanistic	Organic
the specialized differentiation of functional tasks into which the problems and tasks facing the concern as a whole are broken down	the contributive nature of special knowledge and experience to the common task of the concern
the abstract nature of each individual task, which is pursued with techniques and purposes more or less distinct from those of the concern as a whole; i.e., the functionaries tend to pursue the technical improvement of means, rather than the accomplishment of the ends of the concern	the 'realistic' nature of the individual task, which is seen as set by the total situation of the concern
the reconciliation, for each level in the hierarchy, of these distinct performances by the immediate superiors, who are also, in turn, responsible for seeing that each is relevant in his own special part of the main task	the adjustment and continual re-definition of individual tasks through interaction with others
the precise definition of rights and obligations and technical methods attached to each functional role	the shedding of 'responsibility' as a limited field of rights, obligations and methods (problems may not be posted upwards, downwards or sideways as being someone's else's responsibility)
the translation of rights and obligations and methods into the responsibilities of a functional position	the spread of commitment to the concern beyond any technical definition
hierarchic structure of control, authority and communication	a network structure of control, authority, and communication. The sanctions which apply to the individual's conduct in his working role derive more from presumed community of interest with the rest of the working organization in the survival and growth of the firm, and less from a contractual relationship between himself and a non-personal corporation, represented for him by an immediate superior
a reinforcement of the hierarchic structure by the location of knowledge of actualities exclusively at the top of the hierarchy, where the final reconciliation of distinct tasks and assessment of relevance is made	omniscience no longer imputed to the head of the concern; knowledge about the technical or commercial nature of the here and now task may be located anywhere in the network; this location becoming the ad hoc centre of control authority and communication
a tendency for interaction between members of the concern to be vertical, i.e., between superior and subordinate	a lateral rather than a vertical direction of communication through the organization, communication between people of different rank, also, resembling consultation rather than command
a tendency for operations and working behaviour to be governed by the instructions and decisions issued by superiors	a content of communication which consists of information and advice rather than instructions and decisions
insistence on loyalty to the concern and obedience to superiors as a condition of membership	commitment to the concern's tasks and to the 'technological ethos' of material progress and expansion is more highly valued than loyalty and obedience
a greater importance and prestige attaching to internal (local) than to general (cosmopolitan) knowledge, experience, and skill	importance and prestige attach to affiliations and expertise valid in the industrial and technical and commercial milleux external to the firm

The book, The Management of Innovation, is largely devoted to a description of the methods of investigation, a review of the field data, a description of the two kinds of management systems with evidence that they actually occur, and evidence to support the claim that institutions organized according to a mechanistic system are suited to function in stable conditions, whereas institutions organized according to the organic system are suited to function in changing conditions. A review of the data gathered in the study of the environment surrounding the development of the H-6 high explosive at the Naval Ordnance Laboratory, showed that the local environment corresponded very closely to an organic management system, and was far from mechanistic. Furthermore, the particular characterization of the organic management system, as defined by Burns and Stalker, touched directly on many of the environment features which we had already concluded were significant.

Burns and Stalker also comment on the reaction of a mechanistic organization faced with changing conditions. When the challenge is enough to require the adoption of a new plan, the plan must be generated by, or close to, the head of the organization. The philosophy calls for breaking down all jobs into specialized functional tasks; this leads to the creation of staff groups at headquarters for the purpose of generating new plans quickly. The promulgation of such plans, the training of people in their new role, and the control of the system as people learn to function in a new way, calls for new specialists, with task designations such as liaison and expediter, and also calls for increased communication, reporting, and accounting. The tendency to refer all unprecedented decisions to the head man, at a time when so many decisions are without precedent, creates bottlenecks and delays.

The corresponding picture, of the reaction of an organic-system institution to a nonvarying challenge, was not delineated. Extrapolations suggest that such an organization would be inefficient because of the expenditure of time and effort required to get simple things done. Lack of stimulation might lead to apathy. In any case, the organization is unlikely to compete successfully with a mechanistically managed institution well matched to the job. When an understanding of the true state of affairs permeates the organization, the organization is likely to adopt the structure and usages of a mechanistic system which appears to be the one most appropriate for such a challenge.

d. Authoritarian and Dynamic Management Philosophies - Sheldon A. Davis

Sheldon Davis is presently Director of Industrial Relations at the Space Technology Laboratories in Redondo Beach, California, where he is studying the organization of that institution and attempting to influence its activity constructively. As part of his work he has focused attention on the norms

and values associated with particular kinds of organizations and the philosophies of management associated with them. He has distinguished two extreme types, authoritarian and dynamic, and has compiled a brief catalog of important differences in their norms and values, which make it easy to distinguish them and even to form a mental picture of the kind of organization which they describe. His tabulation is contained in Table V-3. This particular formulation has not been published in the open literature, but has been discussed at, among other places, seminars in the Department of Behavioral Science at the Case Institute of Technology. It is reproduced here with the permission of the author.

It is quite clear that the philosophy characterized by Sheldon Davis as authoritarian corresponds to the organizational system which Burns and Stalker characterized as mechanistic; the philosophy he characterized as dynamic matches the organizational system which they called organic. A further check against the data accumulated at the Naval Ordnance Laboratory shows ample evidence that the local environment in which the H-6 high explosive was developed corresponded closely to Davis' pattern of a dynamic philosophy, and failed in almost every detail to match Davis' characterization of an authoritarian philosophy.

e. Innovation-Resisting and Innovation-Producing Organizations - Herbert A. Shepard

The conclusions which Burns and Stalker faced on their studies of Scottish and British industries, and which Sheldon Davis based on his experience at the Space Technology Laboratories and elsewhere, agreed in describing two extreme types of organization and in identifying one type as suitable for operation in a static environment, the other for a changing environment. A particular aspect of response to changing conditions is the way in which innovations are introduced and assimilated in an organization. This has been a special topic of study in recent years by Herbert A. Shepard at the Case Institute of Technology, and is the subject of a paper, "Innovation-Resisting and Innovation-Producing Organization."(9) Shepard's observations are consistent with those common to Burns and Stalker and Davis, and he goes somewhat further in his study of the particular processes through which innovations are introduced or resisted. This has led him to another characterization of organizational systems, in which considerable attention is focused on relations among pairs of people. His particular choice of contrasting pairs* of characteriscics describing a coercion-compromise system and a consensus-collaboration system are reproduced in Table V-4.

*From a chapter to be published in Handbook of Organizations, ed. James March (Rand McNally, 1965).

TABLE V-3

CHARACTERIZATION OF AUTHORITARIAN AND DYNAMIC ENVIRONMENTS

(Sheldon A. Davis, as communicated by James Powers)

Authoritarian	Dynamic
the engineers are "one-up" with respect to non-engineers	the notion that there is one professional staff with the organization with differentiated skills
people should control their feelings, keep personalities out of discussions	open expression of feelings when relevant to the task
very little day-to-day coaching of any real direct nature	feedback in all directions as appropriate
high confidence (sometimes cockiness) in instances	introspection at all levels: intrapersonal, interpersonal, intergroup
handling of differences and conflict resolution through power plays, compromise, flight, arbitration	direct confrontation and problem solving
task oriented communication highly selective, filtered and screened	very open communication
maskmanship	openness
much energy directed inward, off-target, such as repressed feelings of inadequacy	energy related to task oriented functions
deal through stereotypes: e.g., "fifth floor" (executive offices), "electronikers"	breaking through the stereotypes
competition	collaboration
direction from above	direction from all levels
each man looks out for himself	training each other and being consultants to each other

TABLE V-4

COERCION-COMPROMISE AND CONSENSUS-COLLABORATION SYSTEMS
(Characterized by Shepard as transmitted by James Powers)

Coercion-compromise system	Consensus-collaboration system
authority-obedience relationships	mutual confidence and trusting relationships
rewards superficially cooperative behavior and enforces mutually competitive attitudes	rewards commitment to one another and to superordinate goals
structure is power-based	structure is task-based (human interdependence and shared responsibility)
subordinates view supervisors as traditional bosses	subordinates view supervisors as resources to aid in problem-solving
the next solution is built like the last solution	creative atmosphere where new kinds of solutions are actively sought out
concept of supervision, an agent of higher authority	concept of multi-group membership, a catalyst in the maintenance of communication and consensus among interdependent units
the organization an end in itself	the organization is a means which its members control towards ends which are in accord with humanistic values
superordinate power is used to control behavior	control is achieved through agreement on goals, coupled with a communication system which provides continuous feedback of results so that members can steer themselves
management skills possessed by manager	good management is understood to be the emergent product of adequate working relationships

Again it is clear that the coercion-compromise system corresponds to Davis' authoritarian system and Burns and Stalker's mechanistic system, whereas the consensus-collaboration system corresponds to Davis' dynamic system and Burns and Stalker's organic system. In our study it opens a new avenue for data gathering, for this particular selection of contrasted pairs of descriptions is particularly applicable to relations, that is, generalized communication links, between well-defined groups. We were able to compare these two sets of descriptions with the evidence gathered in our study of the H-6 high explosive development environment, and found that the relation between the relevant groups at the Naval Ordnance Laboratory and at the Bureau of Ordnance corresponded very closely to that of a consensus-collaboration system, and was quite far from that of a coercion-compromise system.

f. Marcson, "The Scientist in American Industry"

Simon Marcson has made a depth study of a particular industrial laboratory, which he reports in his book The Scientist in American Industry[10].

In the passage below, Marcson describes two types of authority which he calls "executive authority" and "colleague authority." His description of the accompanying systems of control, which he does not name, are essentially what we mean by authoritarian and adaptive systems respectively.

Systems of Authority in the Industrial Research Laboratory

> "Executive authority*" as a system of control need not be dictatorial, nor must it disregard the rights of individuals. Executives can and do consult their subordinates at times on matters of policy. By one means or another they may seek to gain the consent and participation of their subordinates in the decision-making process. This does not mean, however, that subordinates have power to make decisions without the authorization of their superiors. In the executive authority system, individuals do not establish their own goals or make their own decisions. Therefore, no matter how decentralized or 'participative' the managerial hierarchy may be, the authority rests with the responsible executives. This type of authority accrues to the executive based on his incumbency in a position and 'occurs within the

*Harbison, Frederick and Charles A. Myers, "Management as a System of Authority" in Management in the Industrial World (New York, McGraw-Hill 1959) pp. 40-67.

framework of pre-existing rules of the organization.'* It is not based on either devotion or respect for him as a person, 'but on an adaptation necessitated by his rating power.'**

"Colleague authority, as has been noted, has reference to a system of control which is shared by all the members of the working group. Authority is deemed to rest in the group rather than in an individual. It is true that there is a delegation of decision-making authority to individuals in colleague authority systems, but the members view such authority as originating in the colleague membership.

"In the academic organization the individual is subject to the authority of his professional colleagues. Through the appropriate departmental or divisional machinery they pass judgment on his work, they recommend his promotion, and they determine his status on the basis of professional criteria. They also protect him against an unwarranted exercise of administrative authority. In short, in the academic organization, one's professional colleagues are the ultimate source of authority, whereas in the business corporation the top executives have the supreme power. Matters of general policy regarding teaching and research are presumed to be governed by the appropriate groups of professional colleagues. In the academic organization, the individual faculty member is not subject to the authority of a chief executive or a dean except in specifically circumscribed areas. Indeed, the senior faculty member is insulated from executive authority by academic tenure to insure his freedom of expression and choice of research. Academic administrators can and do lead, persuade, or implore faculty members to follow certain courses of action, but in so doing they may not rely upon a position of authority over the academic community."

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*Merton, R. K., Social Theory and Social Structure (Glencoe, Ill., Free Press, 1949) p. 151.

**Blau, P. M., The Dynamics of Bureaucracy (University of Chicago Press, 1955) p. 173.

g. Gouldner, "Organizational Analysis"(11)

In a continuation of the passage above, Marcson goes on to say:

"What seems to be emerging is a convergence of the industrial organization and university models into a new type of organizational model incorporating elements of university professional status and industrial employee status. In the meantime, as the new model emerges, the two opposing systems of authority are not always compatible. The consequences of this incompatibility may be characterized as strain."

This is an early mention, based on particular observations, of the problem of synthesis between authoritarian and adaptive models of management systems. The subject is taken up in greater detail by Gouldner in his review entitled "Organizational Analysis." First, he describes a rational model and the natural-system model of organizational analysis, which corresponds closely to the models of an authoritarian and an adaptive system respectively. After making a comparison and contrast, he goes on to state:

"My objective is to document the need for a science and reconciliation of the rational and natural-system models. Among these problems are the following:

"1. The authority of the modern administrator is characteristically legitimated on the basis of his specialized expertise....Problems arise, however, when administrators exert control over subordinates whose technical specialties or organizational experience differ from their own.....

"2. Another solution to the problem of exercising authority over unfamiliar specializations involves a self-imposed limitation on the criteria for inspecting and evaluating the performance of subordinates......

"3. A third solution to the problem of legitimating authority over unfamiliar specializations is to define administration as a distinct field in itself, specializing in problems of 'human relations' ....

"4. Also implicated in the strain between authority based on incumbency in office and authority based on technical knowledge are some of the special problems of recruiting, inspecting, and evaluating the performance of technical experts in the modern organization.....

"5. Another tension of modern organizations may also be seen as deriving from the relation between its bureaucratic rationality and its social-system imperatives....."

Finally, he says:

"To summarize, it has been suggested that a major task confronting organizational analysis is the reconciliation of the rational and natural-system models. What is needed is a single and synthesized model which will at once aid in analyzing the distinctive characteristics of the modern organization as a rational bureaucracy, the characteristics which it shares with other kinds of social systems, and the relationship of these characteristics to one another."

Our major conclusions center on the observation that the dominant organizational pattern of the Defense Department is authoritarian, that the most suitable pattern of organization for research and exploratory development is adaptive, and that relations between the types of patterns are strained. These observations confirm Marcson's explicit statement. Gouldner's review in 1960 suggests that sociologists are aware of this problem but that no satisfactory synthesis of the two systems has been fully explained.

h. McGregor, "The Human Side of Enterprise" (3)

The studies cited above place considerable emphasis on people's behavioral patterns and the motivational patterns which underlie their behavior. Until comparatively recently, human motivational and behavioral factors were associated with organizational description and theory, in the form of additional detail and qualifications to round out a description founded on structure and other attributes of the system, external to the human beings who are members of it. The first systematic attempt to base organization theory squarely on human behavior and motivation appears to have been made by Douglas McGregor in his book The Human Side of Enterprise. In this study, McGregor reviews his experience and his reaction to the literature of sociology and management

science, and suggests that assumptions about fundamental patterns of human behavior imply a great part of what is believed about management science. He finds sociologists and management scientists and practitioners describing two different kinds of organizations with two different kinds of management patterns. These organizational systems are somewhat inconsistent, and the inconsistencies can be related to the assumptions about human nature and human behavior on which they appear to be based. He describes these sets of assumptions as "Theory X: The Traditional View of Direction and Control" and "Theory Y: The Integration of Individual and Organizational Goals," as reflected in Table V-5.

Obviously, Theory X assumptions correspond to the mechanistic, authoritarian, coercion-compromise system, and Theory Y assumptions correspond to the dynamic, adaptive, consensus-collaboration system. For the purposes of our study, they are not particularly helpful in reducing data, for they tend to require conclusions about human nature which we are unable to draw directly on the basis of the kind of field data we have accumulated. Nevertheless, this characterization is of interest because it is the first general attempt to found organizational theory principally on assumptions about human nature and human behavior. It shows that placing primary emphasis on human nature and human behavior is a comparatively new trend (1960) in management science.

i. Speculative Extension Into Three Classes

McGregor's hint can be followed further. There is no need to limit sets of assumptions about human nature and human behavior to two sets, or to characterize them solely with the type of description which McGregor has given. A superficial view of the history of thought shows at least three systems of assumptions which men have made about human behavior and the relation of man to the universe. Each one of these has some implications about the way men would plan, organize, and execute an activity in response to their understanding of the environment.

In one extreme philosophy the universe is regarded as deterministic. Every molecule follows a predetermined course, as if by clockwork. The whole plan for past, present, and future is complete. It is usually assumed that this plan could be inferred from observation of the past and present. Only the shortcomings of our observational processes and the limitations of our mind prevent us from knowing what the plan is and anticipating the whole future.

TABLE V-5

TWO SETS OF ASSUMPTIONS ABOUT HUMAN NATURE AND HUMAN BEHAVIOR
(The Human Side of Enterprise, Chaps. 3 & 4)

Theory X: The Traditional View of Direction and Control	Theory Y: The Integration of Individual and Organizational Goals
the average human being has an inherent dislike of work and will avoid it if he can	the expenditure of physical and mental effort in work is as natural as play or rest
because of this human characteristic of dislike of work, most people must be coerced, controlled, directed, threatened with punishment to get them to put forth adequate effort toward the achievement of organizational objectives	external control and the threat of punishment are not the only means for bringing about effort toward organizational objectives. Man will exercise self-direction and self-control in the service of objectives to which he is committed.
	commitment to objectives is a function of the rewards associated with their achievement
the average human being prefers to be directed, wishes to avoid responsibility, has relatively little ambition, wants security above all	the average human being learns, under proper conditions, not only to accept but to seek responsibility
	the capacity to exercise a relatively high degree of imagination, ingenuity, and creativity in the solution of organizational problems is widely not narrowly, distributed in the population
	under the conditions of modern industrial life, the intellectual potentialities of the average human being are only partially utilized

An alternative assumption is that not everything is knowable, but that every phenomenon from the universe is part of a pattern. This may be called an empirical or pragmatic philosophy. The local particulars of this pattern can be discovered by careful observation and reasoning. As more and more observations are accumulated, a more detailed understanding of this part of the universe is developed. This understanding converges on objective truth. However, there is no way to find a master plan for everything for ever and ever. Only a local understanding can be perfected, and valid predictions do not extend forever, but only for a short time.

At another end of the scale is the existentialist view of the universe. The existentialists agree that a good part of our understanding of knowledge and feelings are within us as well as being objectively part of the outside world. What we see is not an objective reality in the sense of the determinists, but only our own reaction to what goes on outside. Objective reality does not exist or is unknowable. All we shall ever know is sensations, emotions, and insights, and the intellectual constructs we can create from them.

Derivable from these three types of suppositions about the universe are three easily distinguishable philosophies of management, illustrated in Table V-6. A deterministic philosophy suggests a master plan. The master, the "fearless leader," knows everything. He can make all decision, he can direct an activity of any scope. He directs by breaking the activity into small tasks and issuing orders describing how each task is to be done. A simple everyday illustration is a do-it-yourself electronic circuit kit, like the ones from which many people have built hi-fi sets. Somebody has gone through the process of designing and wiring an electronic system, identifying everything that must be done and the exact way to do it, and writing out detailed directions. By following the directions, anyone can build the desired circuit whether he understands electronics or not.

Under an empirical philosophy, we can imagine systematic activity which cannot be predicted and programmed in advance. A management plan based on unambiguous deterministic orders would be inadequate; an adequate plan would have provision for making further observations and refining knowledge to overcome the inability to predict in advance. In addition to specific directives, such a plan would include the use of decision rules requiring judgment.

As an illustration of such a plan, consider road directions telling how to get from one city to another. These may consist of detailed (deterministic) directions about which direction to go, how far to go, where to turn, and so forth, leading to a main artery; followed by the general direction "follow the road signs leading to the destination city." Without any detailed knowledge of

TABLE V-6

THREE VARIETIES OF MANAGEMENT PLAN

Prevailing Philosophy of the Universe	Management Philosophy	Nature of Plan	Character of Results	Analogy in Terms of Finding a Path to a Destination
Deterministic	Authoritarian	Step-by-step directions laid out in advance	Solving problems whose method is known and whose solution is implicit in the data	Following a route derived from a road map
Empirical	Adaptive	Decision rules laid out in advance	Discovering things which may be unknown but which already exist to be discovered; solving problems by methods derived from known methods by gradual transformation	Following road signs telling the direction to a chosen destination
Existential	"Dynamic"	Subject to change in response to all stimuli, present and past (particularly the immediate present)	Creative, inventive or innovative discovery	Exploration

1. Each of these three types of programs may contain subroutines. Ordinarily subroutines in an existential-dynamic program belong to any of the three types; subroutines in an empirical-adaptive program are deterministic-authoritarian or empirical-adaptive. Thus the bulk of the detailed activity in any program may be deterministic-authoritarian, whatever the underlying philosophy of the program as a whole.

2. As a field of knowledge begins, develops, and matures, the prevailing philosophy moves from the bottom of the chart towards the top. E.g., Kepler's and Newton's conception of "laws of planetary motion" is typical of activity in the lowest line. When the concept of "laws of motion" is accepted, activity of the middle line suffices to find what the laws are. Today we deal with satellite orbits in a manner typical of the top line. But the transition from Newtonian to Relativistic mechanics starts again at the bottom line.

3. Formal teaching methods follow a reverse course: the student first is taught arithmetic, grammar, etc., in a deterministic-authoritarian program. Later he makes observations and studies case histories, and learns to modify and ramify codified knowledge. Finally, in his Ph.D research or his apprenticeship he may learn to create, innovate, and invent. Informal education, e.g., the way a native speaker learns a language follows the historical upward pattern, and, as in the example of language, may never reach the top line.

where the signs are, we can nevertheless use such a set of directions with high confidence of reaching the right destination. Even if the road network is changed so that the actual route is altered, this program remains adequate without change.

Both of these schemes work if roads have been mapped out. But what happens if roads do not exist? And what happens if we don't know whether there is a city at the other end? This is the situation found in research. At the beginning of a research project, the outcome is not known. Therefore, it is fruitless to define a detailed sequence of operations to reach it. It is even difficult to conceive of a decision rule which would distinguish a desirable outcome from a worthless outcome. The research worker must exercise his judgment on the basis of what he knows, not solely on the basis of decision rules developed by people who have not shared his recent experience. He must decide for himself, then and there, that he has arrived at a worthwhile outcome or that he must push on.

This process is more like exploring unmapped territory than like following a road network. If the result later turns out to be valuable, it is called a discovery, whether it is the consequence of dynamically planned travel or dynamically planned research. The connection with the existential philosophy of the universe is quite close. The outcome is not predicted, decision rules cannot be put into straightforward affirmative propositions. Any achievement rests in part on the explorer's capacity to make worthwhile decisions as turning points and obstacles arise.

Actual systems of management of research and development can be divided into three corresponding classes:

> authoritarian organizations, which in principle attempt to describe all actions in advance;
>
> adaptive organizations, which attempt to define not necessarily the actions but the standards and values which shall be used to decide what actions will be taken; these standards and values are fixed from the beginning; and
>
> dynamic organizations where certain standards and values are agreed on but where it is also agreed that when the protagonist comes to something new he tries to take advantage of what he sees, what he knows, and what he understands; he makes the best choice he can, tells people about it, perhaps, but does not necessarily wait for approval from headquarters.

Different kinds of results are likely to come out of these three programs. No research or exploratory development results will come out of or be assimilated by an organization which functions according to such an extreme authoritarian-deterministic plan. An empirical-adaptive plan should allow much problem solving, and modification of plans by accumulation of small changes. Either one of these would discourage a totally "new" approach, and would be a hostile environment for a "breakthrough."

At first sight, it is implausible that anything is ever learned by dynamic-existential methods. Yet all of us learn a great deal this way. For example, this is the way we learn to talk. No one gives an infant a plan for vocal experimentation. He makes noises, he gets responses. He learns to adapt the noises to the responses, and after a while he learns to make long, highly structured sequences of noises which we call speech. These enable him to communicate, to influence people, and to elicit favorable changes in his environment. Almost everyone who ever succeeds in learning how to talk learns this way.

There are people who learn by an authoritarian mechanism, such as the system which used to be used in secondary school teaching of languages. The grammar is fixed, the rules of syntax are spelled out, the vocabulary is defined by a dictionary. Some people learn to communicate this way, but most people who start this way never even learn to read, let alone to speak or to write. The more modern methods now used for language teaching are adaptive, and appear to give better results. But by the dynamic existential method, most children learn to speak fluently at the age of three or four. With some formal instruction they can read and write at the age of eight or nine. Almost all literature (which is the written part of the creation, innovation, key ideas and breakthroughs in language), is written by people who learn the existential way. Relatively speaking, the other methods are very unsuccessful.

This development of three types of management philosophy is purely speculative. The literature of management science and our field observations give us meager support for it. If, however, we put deterministic philosophies in one class and empirical and existential philosophies in another class, the division corresponds closely to the division between authoritarian and adaptive systems of management and control.

4. Lessons from Other Field Data

a. RXD Event Descriptions

Certain items of environment information are called for in the RXD Event Description, but even in the earliest stages of the study, when we were learning how to collect information for these descriptions, it became clear that our form reflected some misconceptions about research and exploratory development management environment.

The idealization which we have tried to characterize as an RXD Event is not an obvious discrete unit of scientific or technical activity. Various people look at research and exploratory development from various points of view, tend to break it up in pieces according to the field of science or technology, the group of people who worked on it, the purpose which was served by the final product, the source of funding, the institute where the work was done, the contents of discrete scientific publications, the boundaries of inventions as construed by the Patent Office and various other criteria. When these all define the same boundaries, there is no problem. When they did not, the burden of identifying the event lay with us, and the resulting identification was sometimes viewed with a skepticism which made it difficult to get candid information relating specifically and directly to the RXD Event.

Scientific and technical personnel carrying out research and exploratory development are usually ignorant of the formal task statements under which their work of a decade ago was carried, of the ways in which funds were controlled and distributed, and even of the ultimate source of funds. They were comparatively ignorant of the formal organization charts and of the formal review procedures used for technical and other control. On the other hand, they had a lively recollection of personal professional relations with colleagues, with prospective users, with sympathetic representatives of their sponsors, with their sources of technical understanding, insight and inspiration, and with the goals and aims to which they were directing their efforts (in contrast to the nominal goals in their task statements).

As a specific example, we find that almost all the people associated with a project are able to identify a "spark-plug" or source of technical ideas, but many are unable to remember who held the office of group leader or department head, and often they disagree on what the name of the department was. Most of the technical people claim never to have seen the official task statement or any budget planning or control document related to their project. In cases where we have been able to learn the title and funding description of projects, the responsible technical people have indicated that they do not remember or

even recognize them. On the other hand, almost everybody is able to tell where he went for resources such as facilities, technical assistance, specialized consultation, supplies, and addition of personnel; and the various accounts seem to be mutually consistent.

Originally, we regarded this as a weakness in the field investigation procedure, and attempted to compensate for it by collecting information from staff and administrative personnel, and by looking for formal documents and records. In the end, however, we learned to regard this fact in itself as a datum. What is remembered and the terms in which it is remembered serve to point out some of the strong influences on what research and exploratory development scientists do, as opposed to other factors, which exert little influence and about which the scientists are indifferent or ignorant.

The date at which an RXD Event was initiated was much more difficult for most people to remember than the date when it ended. However, the sources of motivation and inspiration for getting the work started, and the people who were involved, seemed to stay vivid in the memory, even when the time and place were recalled only vaguely.

In seeking information about financial support, we very quickly learned that fund juggling of many kinds is widely practiced. It appears to be taken for granted by a large number of research scientists and development engineers that they have no real responsibility for living within the funding controls which are the formal norms of their institutions. We later learned that a statement that time, materials, and facilities were borrowed from other activities charged to other accounts, and a statement that getting the activity started was not discouraged and met with no unusual resistance, are not considered contradictory by R & D workers in the field.

Research and development workers are often ignorant of the actual sources of the ideas which they are exploiting, and the practical applications which have been made of this work. When asked to describe their activity, they are able to place the particular work which they contributed to an RXD Event in a stream of ideas, and identify certain inputs to and outputs from their own activity. But these are not the same sequences which one would use to describe the evolution of a field of science and technology toward practical application in a weapon system. The differences are a reflection of the differences in goals and values between research and development scientists and technologists and the people who are supporting weapon system development procurement use.

b. From the Study of the Mark 46-0 Acoustic Homing Torpedo

Our study of the development history of the Mark 46-0 torpedo was the first to approach completion. Two of its findings contributed to the change in emphasis of our study of environments. First, we discovered that all RXD Events identified within the constraints of this study up to that time (July, 1964) had been stimulated by one or more of four particular conditions:

World crisis (World War II or Korea)
Operational problems observed in other systems
Long-term research in specific technical problem areas
System research and development contracts.

Except for the third of these items, the conditions represented are not part of the normal background of research and exploratory development planning.

The discovery of a relationship between innovative activity and certain special conditions caused us to turn more attention to the particular details which stimulate the initiation of the real activity of research and exploratory development, rather than to the circumstances leading to the issuing of a task order or authorizing of a fund allocation.

A second observation made at that time which did not find its way into the tabulation of conclusions, but which did affect the way in which the program was carried on, is that a great deal of significant technical information and technical stimulation is transmitted by personal contact and word of mouth. Documents are not remembered as sources of information or of stimulation, but rather as backups and references to be used after an initial basis of understanding has been established by personal contact.

5. Checklist of Standard Environment Questions

In the end, we were unable to agree upon an exhaustive list of environment features with enough content to permit us to deduce conclusions of the kind we sought. Instead, we organized a body of hypotheses, broadly resembling the findings reported in Section I, and attempted to determine the information necessary to show that our picture of the environment of an RXD Event was consistent or inconsistent with the particular hypothesis. We elected to describe this scope in terms of eight sets of typical questions, concerned with:

> Timing, with respect to the state of science and technology, to the development cycle of the system in which it was used, and to other related scientific and technical activity.

Personnel involved in various important phases of conception, approval, professional work, and presentation of results.

Motivation.

Atmosphere, including many formal and informal organizational features of the environment.

Financing, including both nominal and actual means for acquiring and allocating resources.

The idea, including its relation to contemporary streams of thought.

Transition, aimed at discovering how the RXD Event came to be used in a weapon system.

Research and exploratory development management, a general category for the inclusion of information outside the scope of the other categories, particularly specific suggestions for the improvement of research and exploratory development management made by respondents when they learned the purpose of our study.

Appendix D contains the Standard Environment Questions, as actually distributed to the staff. It is accompanied by a brief covering memorandum which states how this list of questions is intended to be used. This memorandum is only a reminder, for the staff members who undertook responsibility for summarizing the environment information spent many hours together in a series of conferences, drafting and redrafting sets of questions, exploring the consequences of various formulations, trying them out on a few specific RXD Events, and suggesting further refinements. Thus the list of environment questions and the instructions represent, for the people who used it, a tangible reminder of a considerable group effort. It is not expected that it would mean the same thing to a person who did not participate in these conferences.

There was no formal routine for using these questions. They were never posed directly to respondents. Freely structured interviews were used, carried on permissively, with criticism avoided. The interviewer carefully avoided evaluating the respondent, the environment, or the data while carrying on the interview. Where the data did not fit the character of the questions, the form of the questions was abandoned and data was accumulated in whatever form the respondent was able to talk about it. Respondents were assured that their

confidences would be respected. Where later evaluation suggested that the data were incomplete, doubtful points were clarified by follow-up visits, phone calls, and other means. In most cases, after a satisfactory interview was carried out, the interviewer was able to give an unequivocal answer to most of the questions in this list, or to formulate a question which educed comparable information, or stated that the question did not apply in the case at hand.

We, nevertheless, believe the data to be valid for a number of reasons. First, a personal relation of trust is established between the interviewer and the respondent. People know how to withhold information, and the various conversational gambits which are used when they are doing so are easily recognized by experienced interviewers. However, when the respondents do undertake to confide, most of what they say is likely to be sincere. Secondly, the data are highly redundant; fifteen interviewers have talked to several hundred respondents, and their impressions have been consistent. Third, the data tend to confirm the personal experience of the interviewers and other ADL staff members who have had recent experience as consultants in problems of research and exploratory development management. Finally, the results are consistent with the conclusions recently drawn by other investigators, particularly those described in Section V-C.

As the data in the study involving the Standard Environment questions were reduced, a number of specific hypotheses were framed in the form of tentative conclusions. The data were then re-examined to see if they supported the hypotheses in the particular form in which they were worded. In a large number of instances, we were led to frame additional specific questions about each event. These questions were answered by our staff members on the basis of information in their notes and in their memories, usually without recourse to our respondents or to new sources. They reflect the judgment of our interviewers, but may be based on information from several sources. These questions and the answers to them are displayed in Appendix E. The answers are explained in two ways. First, Table E-1 shows a coded machine computer print-out of answers to each question and each event. In order to protect the interests of our sources, the identity of the individual RXD Event is not given. However, each horizontal line is a consistent set of answers for one particular RXD Event. Figure E-2 shows the distribution of answers to each question, first for 11 R Events, then 52 XD Events, and finally for the total population of 63 Events. Most of the quantitative statements in Section II are based on these specific environmental questions.

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APPENDIX A

(Excerpt from the work statement to which this study is responding)

SCOPE OF WORK

The primary objective of this study is to discover relations between the environment in which research and exploratory development projects are carried out, and the extent to which the results of these projects are subsequently exploited in operational weapons systems. Arthur D. Little, Inc., will find these relations by tracing the development history of a selection of operational weapon systems back to key ideas; examining the technical, organizational, and fiscal environment in which the key ideas were generated; and comparing this environment with the general environment in which research and development was carried out at that time. Arthur D. Little, Inc., will test hypotheses based on observed differences by examining further case histories, until satisfactory agreement between hypotheses and observations is achieved.

Another objective of this study is to gather and systematically display data uncovered in pursuing the primary objective which may be useful in further studies augmenting the present study or otherwise related to it in subject matter, which the Department of Defense may cause to be carried out. Arthur D. Little, Inc., will document its work toward the primary objective and simultaneously achieve the other objective by submitting a final report, regular monthly letter reports, and copies of working documents, and by discussion with representatives of the government as described below under the heading REPORTS.

The approach to this investigation will follow generally that suggested under STATEMENT OF THE PROBLEM AND METHOD OF APPROACH below. It is recognized, however, that the research methodology basic to this undertaking has not previously been established. Therefore, the method of approach to this investigation, the selection of systems, sequence of steps, and the distribution of emphasis and effort on specific aspects of this investigation may be changed from time to time at the request of the Department of Defense Project Director or upon the request and recommendation of the contractor, subject to mutual agreement on the alternate course of work to be undertaken.

STATEMENT OF THE PROBLEM AND METHOD OF APPROACH

The Department of Defense has spent many billions of dollars in the last 10 or 15 years on research and exploratory development. The results of these research and exploratory development efforts were thereafter available to the designers and developers of weapons systems and other operational equipment. Some research and exploratory development results have been used in

weapons systems, some have not. Among those which have been used, some are crucially important technological resources without which the stream of development could not have continued, others were desirable but not essential alternates to other available resources. Those research and exploratory development projects whose results have been used we shall call utilized, and those whose results have not been used we shall call unutilized. The quality of being utilized is one measure of the value of research and development.

Certain environmental factors can be selected or controlled by the Defense Department when research and exploratory development is procured. By manipulating these factors, the Defense Department might be able to influence the degree of subsequent utilization of the results.

The central problem of this study is to discover relations between the technical, organizational and fiscal environment surrounding research and exploratory development projects and the degree to which results of these projects are subsequently utilized. Particular attention will be paid to finding environmental patterns associated with successfully utilized research and development, and to finding relations which might allow the Defense Department purposefully to influence potential utilization by selecting or controlling environmental factors.

Arthur D. Little, Inc., will begin by choosing one or more operational weapon systems, and tracing the history of their development back in time, identifying the key ideas whose introduction made the development possible.

The key ideas are those ideas without which the system concept could not have been generated, or without which it could not have been executed, or without which the final operational embodiment of the system would have to be substantially different. It is expected that, after a few instances are studied, there will be general agreement about what constitutes a key idea for the purpose of this study. If not, it will be necessary to agree upon a compromise for the sake of uniformity.

Arthur D. Little, Inc., will then trace the key ideas back to their sources in research and exploratory development and will study and describe the patterns of organizational, technical, and fiscal environment in which the key ideas were generated. These sources will be found by looking at technical and contract documents generated during later phases of development and by talking to key investigators and appropriate management personnel who participate in various developmental phases.

The investigation shall include the technological description of each key idea as well as the full description and interpretation of the environment associated with each, including but not necessarily restricted to the circumstances of initiating, planning, contracting, fincancially supporting, organizing, staffing, controlling, evaluating, and utilizing the results of each key idea.

At the same time, Arthur D. Little, Inc., will study the environmental patterns of a sample of research and exploratory developments projects supported by the Department of Defense, which is unbiased with respect to utilization of results. When these patterns are compared, we expect to see differences. From these differences, we shall formulate hypotheses about the relationship of environmental factors to degree of utilization.

It is desirable to seek hypotheses based on environmental factors which have some predictive value, that is, on features of the environment which can be measured at or before the time that research and development is carried out, and well in advance of the time when the utilization of results can be determined unequivocally. It is also desirable to focus attention on those factors which could be selected or controlled by the Department of Defense.

It is probable that the amount of data available from the case histories of the initial sample will be insufficient for a valid test of the hypotheses. Therefore, more case histories will be studied. Arthur D. Little, Inc., will carry on a continuous refinement both of the amount of data sought and the details of the hypotheses, until satisfactory agreement between observations and hypotheses is achieved.

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APPENDIX B

RXD EVENT DESCRIPTION

(Outline for use in guiding field work and reporting status. The outline should be followed as closely as practicable; where specific information is lacking or must be qualified, the corresponding item of the outline should explain such limitation or be left blank; item 14 is intended for miscellaneous comments or information not appropriate elsewhere in the outline.)

1. Title

A short descriptive title identifying the activity (e.g., development, demonstration, investigation, study, etc.) which culminated in understanding of phenomena, demonstration of principles, or specific embodiment of principles (e.g., technique, device, material, etc.).

Note: An RXD event is conceived here as corresponding to a period of technical activity with a well-defined end point (e.g., the preparation of a report, presentation of a technical paper at a professional society meeting, patent disclosure, demonstration of a working model, etc.). Typically, a creative or innovative act is involved. Care should be taken to avoid: (1) inclusion of normal engineering activity within the contemporary state-of-the-art, (2) lumping a number of RXD events into an ill-defined class of such activity, and (3) confusing manufactured hardware with RXD events.

2. Weapon System

Name, including the standard nomenclature and the common name, if needed, for easy identification. (The term "weapon system" refers to entries in the Weapons Dictionary of the Secretary of Defense.)

3. Subsystem

Reference to an analysis of the weapon system into immediate and separately identifiable constituents, arbitrarily adopted as standard for the purposes of this study.

Note: For this purpose, over-all System Concept, Aerodynamic Configuration, etc., will be treated as subsystems where considered appropriate.

4. Element

Reference to an analysis of the subsystem into immediate and separately identifiable components, considered as involving RXD events.

> Note: For this purpose, the Subsystem Concept, or the subsystem itself, as defined above, will be treated as an element where considered appropriate.

5. Technical Significance

a. A brief paragraph describing as concisely as possible the important technical content of this event, followed by more detailed paragraphs describing the technical content of the RXD event, including its origins, the technical activity, and the outcome, specifying where possible the resulting materials, techniques, publications, patents, etc.

b. A brief statement of the relationship of the RXD event, described in 5a, to the contemporary status of science and technology (e.g., the first example of the application of existing principles or techniques to perform a function, etc.).

c. A brief statement describing the relationship of the RXD event to the system or subsystem performance or to the succeeding related application in the chain connecting it to the system in question.

6. Type of RXD Event

A short statement clarifying the generic nature of the event: e.g., scientific research, exploratory materials development, manufacturing process development, patented invention resulting from design engineering, etc. The purpose of this statement is to assist in classification of RXD.

7. Key Personnel

The names of the individuals having a significant role in the RXD event with a brief description of their role and of their background and experience. Such individuals may be employed in the organization where the RXD was performed, in a Government project office or laboratory, or elsewhere.

8. Date of Event

a. The year in which the specific RXD event activity terminated (see 1 above). A more detailed specification of date should be included when available.

b. A starting date, approximate or estimated if necessary, consistent with the interface activity preceding the RXD event, described in 13 below, should be indicated. These initial and final dates should also be consistent with the financial descriptions of item 12.

9. Duration

The approximate length(s) of time covered by the specific technical activity having the termination in 8 above.

10. Organization

The names of:

a. the institutions,
b. the organizational subdivisions, and
c. the specific organizational components or project groups within which the RXD event was either performed or conceived, or where significant supervisory or other related decision-making occurred.
d. a brief description of the organization including the interrelationships among a, b, and c and/or any special features of c that help to clarify the nature of the organization.

Note: Organizations other than that where the RXD event was performed (e.g., a Government project office or laboratory) may have played an important part in the RXD event and should also be identified where appropriate.

11. Organization Type

The generic types of organization corresponding to 10 above. This should contain sufficient descriptive material to clarify fully the types of organization and organizational subdivision in question: e.g., industrial (profit) - corporate - research laboratory, industrial (profit) - operating division - design engineering organization, university operated Department of Defense research laboratory, etc. The purpose of this paragraph (see also 6 above) is to assist in the classification of organization types.

12. Financial Support

Specific information on:

a. The source(s) of funds. This should include information both concerning the internal accounting treatment of the funds used and the ultimate sources of funds. Where the work is sponsored by the Government or other sources external to the organization (10 above) specific contract

or subcontract numbers should be identified where possible. Where the decision is made by the organization (10 above) to initiate the activity represented by the RXD event, the way in which the costs are recovered or treated should be clarified (e.g., the expression "company funds" should refer only to the non-recovered expenditure of a company's earned surplus; where subsequent recovery in the sale of products or in negotiated overhead on government contracts is involved, it should be so stated).

b. The time duration of <u>each</u> source of funds.

c. The total cost corresponding to each source of funds. If the source supported more than the RXD event in question, give an estimate, if necessary, of the portion attributable to the event. In general, estimates should be given where specific cost data is either unavailable or withheld.

Note: Cost information should be given in terms of total (i.e., fully burdened) cost and such estimates should be formed, where possible, if the accounting practice of the performing organization differs in this respect.

13. <u>System Interface Activity</u>

a. Information concerning the way in which the RXD event was utilized, that is, the steps by which it was incorporated either in subsequent, related RXD events or systems or in 2, 3, or 4 above. Wherever possible, specific events should be identified: e.g., the preparation of a proposal, etc.

b. Information concerning prior RXD events, system activity, or incidents which contributed to, influenced, or provided a motivation for the RXD in question. In particular, where Government sponsorship of the RXD work is involved, identify whether the <u>technical</u> initiative resided in the performing organization, the Government, or elsewhere.

14. <u>RXD Event Circumstances</u>

Miscellaneous information relating to the RXD event but not elsewhere classified. Management environmental information may be recorded here. Wherever, because of the nature of the RXD event, it is possible to demonstrate a relationship between the cost of the RXD event and the cost savings to the Government of either the final weapon systems or specific delivered hardware, this information should be identified and reported here.

15. <u>Sources</u>

Documents, persons interviewed;etc.

At the bottom of the first page the author's name at the left hand side and the date of issue at the right hand side.

LXD EVENT DESCRIPTION NO. 20

1. TITLE

Development of pyrolytic graphite

2. WEAPON SYSTEM

Polaris
Minuteman

3. SUBSYSTEM

Propulsion

4. ELEMENT

Nozzle Throat Inserts

5. TECHNICAL SIGNIFICANCE

a. Origin, technical activity, and outcome - This event consists of the development of techniques for the preparation of sound thick sections of highly oriented pyrolytic graphite.

Pyrolytic graphite was known in the nineteenth century, in the form of a hard carbon product of carbon-producing furnace operations, and Edison considered it as a lamp filament material. In 1952, it was studied in England as a coating for graphite material of construction for the gas cooled nuclear reactor, but was given up because of unsolved structural deficiencies. In 1956, a materials research group at Raytheon Corp. began work with the material because of its potential as a low permeability coating for the porous bulk graphite to be used in the Raytheon concept of a liquid-metal-fueled, gas-cooled nuclear reactor.

In the prior work, hard carbon was deposited onto resistance-heated graphite rods by decomposition of hydrocarbons at the rod surface; the hard carbon product was subjected to excessive internal stresses, because of changing temperatures due to the thermal insulating effect of the growing deposit. The Raytheon group, however, was concerned with coating shapes with cylindrical cavities, and studied the deposition of the carbon on the interior of hollow cylinders, rather than as an external coating.

The deposition parameters investigated were temperature, furnace design, hydrocarbon feed compound, and gas flow rates. It was found that a furnace

design having a hot wall at uniform temperature was required, so that the furnace hot zone would approach a black body cavity with uniform temperature distribution. With the furnace hot zone at temperatures of 3500°F to 4500°F, specimen shapes could be coated uniformly by thermal decomposition of methane. The sensitivity of the methane to premature decomposition, when exposed to intermediate temperatures, was recognized and overcome by cooling the supply tube into the furnace interior. The tendency of the feed stream to be depleted of carbon in the vicinity of the supply tube exit was avoided by injecting the gas at high velocity, thus distributing carbon-rich gas along the entire length of the deposition region. With the gradual optimization of these conditions, structurally sound monolithic sections of pyrolytic graphite of moderate thickness could be grown by deposition from the vapor phase thermal decomposition of methane.

The examination of specimens showed that the material was deposited as an assembly of graphitic crystallites, with a very high degree of orientation parallel to the surface of deposition. The deposited material had very low permeability normal to the surface, very high thermal and electrical conductivities parallel to the surface and low thermal and electrical conductivity normal to the surface. These results were brought to the attention of SPO in early 1958. The material was considered to have potential for re-entry as well as for propulsion components.

b. Relationship to contemporary science and technology - The RXD event demonstrated the feasibility of preparing pyrolytic graphite in the size range of interest for functional shapes. Although properties of potential interest were demonstrated, the earlier methods of preparation failed to produce a material free of structural faults--cracks and delamination--in modest sized pieces. This RXD event, which permitted the manufacture of test material and functional shapes was the successful development of a process for the deposition of sound highly oriented graphite by high temperature pyrolysis of gaseous hydrocarbons. The development included the principles for design of a furnace, delineation of the process parameters of temperature and gas flow rates, and development of auxiliary fixtures, all of which were advances beyond the prior state of the art and necessary to the accomplishment of the RXD event.

c. Relationship to succeeding development or to system performance - The initial importance of pyrolytic graphite to the propulsion subsystem was that its high surface-parallel thermal conductivity and low surface-normal conductivity was its potential for reducing the nozzle insulation problem substantially. Early prototype tests with small moderate-temperature rocket motors showed very promising behavior.

6. TYPE OF RXD EVENT

Exploratory development of a process whose product was not fully characterized.

7. KEY PERSONNEL

E. Keon, Chemist, Reactor Materials Development, Chief, Materials Section, Raytheon Nuclear Power Group
D. Keegan, Mechanical Engineer, Thermal Analysis
Dr. D. Schiff*, Physicist, Reactor Physics
R. Russel, Chemical Engineer, Reactor Materials Development

These people were all members of the Raytheon Nuclear Power Group and had previously worked together on the Canel Project. They subsequently left Raytheon and set up an independent company to manufacture pyrolytic graphite shapes.

8. DATE OF EVENT

a. Termination - 1957

b. Initiation - 1956

9. DURATION

1 year to initial accomplishment, with continued development effort for a second year.

10. ORGANIZATION

a. Institution - Raytheon Company

b. Subdivision - Research Division, Nuclear Power Group

c. Group (s) - Materials Section

d. Description - The Nuclear Power Group at Raytheon had been set up to exploit the feasibility of the liquid metal-gas cooled reactor and was housed in the Research Division for convenience. The Materials Section was a closely knit segment of the Nuclear Power Group with very high internal esprit de corps. There was little interaction of the Section with the rest of the Research Division.

11. ORGANIZATION TYPE

Company owned and operated basic research and development division housing occasional entrepreneurial groups such as the Nuclear Power Group.

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*Biography, American Men of Science

12. FINANCIAL SUPPORT

a. Source - Raytheon Company. Funds available from a negotiated overhead allowance for research and development in company's production contracts with DOD were not recoverable for the effort in the Nuclear Power Group.

b. Duration - General 3-year plan, on an "as required" basis without formal allocation.

c. Amount - Specific determination of funds not available. Funding estimated from manpower of four professionals and two-three technicians to be about $150,000.

13. SYSTEM INTERFACE ACTIVITY

a. With contemporary and succeeding activity - Development of the properties continued under company support. The accomplishment brought to the attention of the Special Projects Office early in 1958, following the industry-wide solicitation of late 1957, was funded by the Re-entry Section. Because of its unusual thermal properties, the pyrolytic graphite appeared to have exceptional promise to resolve the thermal protection problem of the re-entry vehicle. The fundin_ also covered the preparation of test nozzles. These were found to be effective under test with solid propellants. The process development was then expanded and aimed, among other areas, at preparation of nozzles for the Polaris. When successfully accomplished, the know-how was also directly applied to the manufacture of nozzle components for the Minuteman.

b. With previous activity - The motivation for this RXD event was independent of any weapon system activity, but was derived from the requirements of the liquid metal fueled, gas-cooled nuclear reactor. A tentative Raytheon conceptual design for such a reactor required that graphite be a major material of construction and that the graphite be impermeable to the diffusion of the coolant gas. After the earlier work in England and general knowledge of hard carbons, the effort was undertaken to prepare an impervious coating on graphite by gas phase thermal decomposition of hydrocarbons. While the material was found to be essentially impervious to the passage of helium, its mechanical and thermal properties were unique, and it was brought to the attention of the Special Projects Office as a thermal protection material. It was at the Government's request that the process development was extended to the nozzle configuration.

14. RXD EVENT CIRCUMSTANCES

The management environment surrounding this event would be classed as permissive as opposed to authoritative. This management philosophy was promulgated by Dr. I. Getting, then Director of Research and currently President of Aerospace Corporation, who believed that the scientific and project staffs should have a free hand. Budgetary controls and formal paperwork were almost non-existent. These attitudes extended down from project leaders to working groups.

15. SOURCES

Interview with H.F. Boyd of the administrative staff of Raytheon Corp., Research Division. (Boyd probably has title of Assistant Director of Division.)

APPENDIX C

TABULATION OF RXD EVENTS

The following list contains some abbreviated information about each RXD Event identified in this study, and a short description of the technical content of the Event. The meaning of the various abbreviations is illustrated as follows, using the first Event as an example.

No. 1 (XD) Bastress — Development of composite solid propellants

This event consisted of the development in 1942 of a new solid propellant for rocket motors, made of potassium perchlorate mixed with molten asphalt, which would harden into a tough solid upon cooling, and which could be cast into a solid grain of any desired shape.

1941-42 GAL/CIT Minuteman, Polaris, Mark 46, Sergeant

NO. 1

This is a serial number designation for identification purposes only. The numbers are not consecutive for serial numbers have been allocated to presumptive RXD Events which were later rejected because they failed to meet various standards.

XD

"R" designates Research; "XD" designates Exploratory Development; "AD" designates Advanced Development (and "I" designates Invention).

BASTRESS

The last name of the author(s) published as a source for further information about this Event Description.

DEVELOPMENT OF COMPOSITE SOLID PROPELLANTS

The title of the Event.

1941-42

This Event was initiated in 1941 and ended in 1942.

GAL/CIT

This Event was done at the Guggenheim Aeronautical Laboratory at the California Institute of Technology. Those abbreviations whose meaning may be oscure are identified below.

MINUTEMAN, POLARIS, MARK 46, SERGEANT

The outcome of this Event or some consequence of its use was found by us to be utilized in the Minuteman, Polaris, Mark 46, and Sergeant weapon systems.

Laboratory	Abbreviation
Allegheny Ballistics Laboratory	ABL
Applied Physics Laboratory/ Johns Hopkins	APL/Johns Hopkins
Applied Physics Laboratory/ University of Washington	APL/U. of Wash.
Bell Telephone Laboratories	BTL
Bureau of Ordnance	BuOrd
California Institute of Technology	CIT
David Taylor Model Basin	DTMB
Guggenheim Aeronautical Laboratory/ California Institute of Technology	GAL/CIT
General Electric	GE
Jet Propulsion Laboratory	JPL
Naval Air Missile Test Center	NAMTC
Naval Ordnance Laboratory	NOL
Naval Ordnance Test Station	NOTS
North American Aviation	NAA
Pennsylvania State University/ Ordnance Research Laboratory	ORL

No. 2 (XD) Bastress	*Application of thermosetting polymers to composite solid propellants		
	This event consisted of the development of an improved solid propellant, using a polysulfide resin as a fuel-binder.		
	1945-47	JPL	Minuteman, Polaris Mark 46, Sergeant
No. 3 (XD) Bastress	*Conception of case-bonded, radial-burning solid propellant rocket motor		
	This event consisted of an exploratory development of a new concept in solid propellant rocket motor design.		
	1946-48	JPL	Polaris, Sergeant, Minuteman
No. 4 (XD) Bastress	Development of castable, double-base propellants		
	This event consisted of the development of castable, double-base propellants for use in large, long-duration thrust units.		
	1944-45	Carnegie-ABL	Minuteman, Polaris (A-2 & 3)
No. 5 (XD) Gallagher	*Development of fluid injection for thrust vector control		
	This event consisted of the successful application of shock wave theory to flight control of a vehicle propelled by a jet or rocket engine, and demonstrated that a secondary jet of fluid directed into the main stream of engine exhaust gases would induce a shock wave in the nozzle, diverting the thrust vector to an extent greater than that provided by the secondary reaction thrust alone.		
	1948-51	United Aircraft	Minuteman (WS-133) Polaris (A-3)
No. 7 (XD) Bastress	Development of polybutadiene fuel-binder		
	This event consisted of the laboratory development of a new polymer material to replace those in current use as fuel-binders in composite solid propellants.		
	1952-54	Thiokol/ Redstone	Minuteman

* The 63 RXD Events on which the environment studies are based are indicated with an asterisk*.

No. 8 (XD) Bastress — *Development of polyurethane fuel-binder

This event consisted of an intensive investigation of polymeric materials for use as fuel-binders in solid rocket propellants.

1954-55	Aerojet-General	Polaris, Minuteman

No. 9 (XD) Bastress — *Use of aluminum to increase the specific impulse of solid propellants

This event consisted of a combined theoretical and experimental investigation of the effectiveness of metal fuels in increasing the specific impulse of composite solid propellants.

1954-56	Atlantic Research Corp.	Minuteman, Polaris

No. 10 (XD) Bastress — *Aluminum additive for control of combustion instability in solid propellant rockets

This event consisted of the recognition and experimental verification of the utility of adding aluminum powder to rocket propellants to control combustion instability.

1955-56	Rohm & Haas	Minuteman, Polaris

No. 11 (XD) Bastress — *Development of composite-modified double-base propellants

This event consists of the development of a new class of propellants combining characteristics of two previously used classes: composite and double-base propellants.

1957-58	Hercules	Polaris (A-3 & 3) Minuteman

No. 12 (XD) Bastress — *Conception and demonstration of the pyrogen igniter

This event consisted of the conception of a new approach to the design of igniters for solid propellant rocket motors, and an experimental investigation of the concept.

1955-56	Thiokol/ Redstone	Polaris (A-2 & 3) Minuteman

No. 13 (I & XD) Bastress — *Exploratory development of thrust reversal methods for solid propellant rocket motors

This event consisted of an analysis of a means for providing thrust reversal capability for a solid propellant rocket, and an experimental demonstration of the validity of the concept.

1955-56	Thiokol/ Redstone	Polaris, Minuteman

No. 14 (I & XD) Bastress

Conception and demonstration of thrust vector control (TVC) by mechanical spoilers (jetevators)

This event consisted of the conception and demonstration of the use of mechanical spoilers for controlling the direction of thrust in a solid propellant rocket.

1951-56 NAMTC Polaris (A-1 & 2)

No. 15 (XD) Bastress

*Development of swiveled nozzle for thrust vector control (TVC)

This event consisted of a program of exploratory nozzle development with the objective of developing a rocket nozzle with a swiveled exit section.

1955-57 Thiokol/Redstone Minuteman

No. 16 (I & XD) Bastress

*Conception of canted rotatable nozzle for thrust vector control (TVC)

This event consisted of the conception and design study of a novel approach to thrust vector control in solid propellant rockets.

1958-58 APL/Johns Hopkins Polaris (A-2 & 3)

No. 17 (XD) Bastress

*Development of nitroplasticized polyurethane composite propellant

This event consisted of an exploratory development effort to produce a solid propellant with improved performance and physical characteristics over those of propellants used in Polaris A-1.

1956-61 Aerojet-General Polaris (A-3)

No. 19 (XD) Bovarnick

Development of consumable electrode vacuum arc melting process for forgeable refractory metals

This RXD event was the exploratory development of the consumable electrode vacuum arc melting process for casting a forgeable billet for the refractory metal molybdenum.

1943-44 Climax Molybdenum Minuteman, Polaris

No. 20 (XD) Bovarnick

*Development of pyrolytic graphite

This event consists of the development of techniques for the preparation of sound thick sections of highly oriented pyrolytic graphite.

1956-57 Raytheon Polaris, Minuteman

No. 21 (XD) Bovarnick

*Invention of composite silver infiltrated porous tungsten rocket nozzle

This RXD event consisted of the invention of the concept that a tungsten rocket nozzle could be protected against degradation due to rocket exhaust gases, by impregnating porous tungsten with a fusible material, which would vaporize and carry away thermal energy in excess of tolerance limits for stability and integrity of the tungsten.

1959-60	AVCO/Wilmington	Polaris (A-3, Stage 1)

No. 22 (XD) Bastress

*Conception and development of filament-wound cases for solid propellant rockets

This event consisted of the conception of a new approach to the fabrication of rocket motor cases, and the experimental investigation of that concept.

1947-49	Kellogg	Minuteman, Polaris (A-2 & 3)

No. 23 (XD) Bovarnick

*Development and analysis of filament-wound closed-end pressure vessel

This event consisted of the development of the analytical applied mechanics of the behavior of filament-wound reinforced plastic closed-end pressure vessels.

1952-55	Young Development Labs.	Minuteman, Polaris

No. 24 (AD or possibly XD) Rudenberg

*Development of reliable integrated circuits

This event consisted of the development of integrated circuits with technical characteristics and reliability sufficient to incorporate them in the guidance computer of the Minuteman weapons system.

1962-64	Texas Instruments	Minuteman

No. 25 (R) Bovarnick

*Development of high temperature shock tube

This RXD event consisted of experimental research, culminating in the development of the high temperature shock tube, a device for producing a controlled high velocity gas stream at ultrahigh temperatures.

1949-50	Cornell U.	Minuteman

No. 26 (R) Bovarnick

*Identification of transition between laminar and turbulent flow on blunt-nose body in high-speed air streams

This RXD event consists of the experimental finding that in an air stream at high velocity incident upon a blunt-nose body, the flow pattern undergoes a transition from laminar to turbulent at much lower Reynolds numbers than previously predicted.

1955-56 AVCO/Everett Minuteman

No. 27 (XD) Bovarnick

*Recognition of the inadequacy of heat sink for re-entry

This RXD event was the experimental recognition of the inadequacy of the high conductivity copper heat sink for thermal protection of the re-entry vehicle.

1955-55 AVCO/Everett Minuteman

No. 28 (XD) Bovarnick

*Prediction and ablative behavior and flight test of quartz heat shield

This RXD event consisted of predicting the ablative behavior of a quartz heat shield under the conditions of atmospheric re-entry, and verifying those predictions with an actual flight test.

1957-59 AVCO/Everett Minuteman

No. 30 (XD) Bovarnick

*Discovery of the principle of ablative cooling

This event consisted of the discovery of ablative cooling as a means of thermal protection.

1952-53 Redstone Arsenal Minuteman, Polaris

No. 32 (XD) Rudenberg

*Development of a useful data processor using digital integrated circuits

This event consists of the completion of a data processor computer (an arithmetic unit), using a group of digital integrated circuits performing logic and switching functions, each functional element being on a single monolithic silicon wafer.

1958-61 Texas Instruments Minuteman

No. 35 (I & XD) Freeman

*Invention and development of a shaped line explosive charge

This event consisted of the invention and development of a reliable explosive device for cleanly rupturing the mylar diaphragm which seals the mouth of the Polaris launch tube.

1957-58 Stanford Research Inst. Polaris (Fleet ballistic missile)

No. 36 (XD) Freeman	*Conception of bare-missile, air-ejected submerged launching This event consisted of the conception of bare-missile launch for a large missile ejected from a submarine, and exploratory analytic work to identify technical problems requiring significant experimentation or test. 1956-56 Lockheed Aircraft Polaris	
No. 39 (XD) Heuchling	*Development of two-degree-of-freedom (free) gyroscope with a spherical hydrodynamic gas bearing supporting the gyro wheel This event concerns the development of a two-degree-of-freedom (free) gyroscope in which the gyro wheel is supported in a spherical, hydrodynamically generated gas bearing. Thus, hydrodynamic support in a single bearing was used to enhance spin-axis bearing reliability, and to enhance gyro accuracy by minimizing gimbal-bearing friction. 1954-56 NAA Minuteman	
No. 40 (I & XD or possibly XD) Rudenberg	*Conception and demonstration of integrated semiconductor circuits This event consists of the demonstration of the feasibility of fabricating a complete electronic circuit, capable of performing a simple circuit function, out of one piece of semiconductor material, combining in this the functions of amplification, resistance, capacitance and other component attributes by processing all the equivalent elements for the complete circuit in a monolithic bar of pure silicon. 1957-58 Texas Instruments Minuteman	
No. 41 (XD) Heuchling	Development and flight test of the FEBE system This event consisted of exploratory system development of a non-radiating navigation and bombing system, and of proving the compatibility of a number of new components and subsystems by incorporating them in a flyable model. 1946-49 MIT Instrumentation Lab. Sergeant, Hound Dog, Polaris, Minuteman	

No. 42 (I & XD or possibly XD) Heuchling

Development of improved ballistic-missile guidance system

This event concerns the conception and development by the Germans at Peenemunde late in World War II of an inertial guidance system for V-2 rockets, which anticipated the basic form of the most advanced systems for ballistic missiles in use today.

1944-45	Peenemunde	Sergeant, Polaris, Minuteman

No. 43 (XD) Sykes/ Mazuy

*Development of doppler enabler

This event consisted of the development of a simple and effective circuit for correcting the frequency shift caused by the forward motion of an active acoustic torpedo, thus permitting the use of a filter to remove reverberation.

1953-54	NOTS	Mark 46

No. 44 (AD) Gallagher

Achievement of twilight astrotracker capability

This event consisted of the redesign of the tracking dynamics of the KS-120 Astrotracker, to achieve substantially better twilight capability.

1957-60	Kollsman	Hound Dog

No. 45 (I & XD or possibly I & AD) Gallagher

*Development of raster-chopper and shutter-scanning system

This event consisted of the development of a means for evaluating the magnitude and direction of tracking error perceived by a star-seeking telescope, and for converting the perceived error into correction data for input to the navigational computer.

1948-52	Kollsman	Hound Dog

No. 47 (XD) Heuchling

*Development of disc memory for digital navigational computer

This event concerns the development of a compact, reliable, low-capacity memory for the continuous, high-speed circulation of digital data as appropriate in a digital differential analyzer.

1952-54	NAA	Hound Dog, Polaris, Minuteman

No. 48 (XD) Heuchling

*Development of pendulous integrating accelerometer

This event involved the conception, design and feasibility testing of a small, simple, and extremely precise integrating accelerometer.

1954-57	NAA	Hound Dog, Minuteman Polaris (SINS)

No. 49 (I & XD) Heuchling

Development of gun sight incorporating a gyro as rate sensor and analog computer

This event concerns the conception and development of the first gyroscopic lead-angle computing gun sight for shipboard anti-aircraft guns.

1940-41	MIT Instrumentation Lab.	Sergeant, Hound Dog, Polaris

No. 50 (XD) Heuchling

Development of the microsyn as a precise torque generator for application to computing gyroscopes

This event involves the conception and development of the microsyn--a small, rotary, differential-reluctance, torque motor capable of developing torques precisely related to excitation current.

1942-42	MIT Instrumentation Lab.	Sergeant, Hound Dog, Polaris

No. 51 (AD) Heuchling

Development of digital readout and control of gyros, accelerometers and platform gimbals

This event consisted of the development of digital readout, control, and driving circuits for gyros, accelerometers, and platform gimbals, using established principles and techniques to solve the interface problems arising between a digital computer and an analog inertial measuring and control system.

1954-57	NAA Autonetics Div.	Hound Dog, Polaris, Minuteman

No. 52 (I & XD) Heuchling

*Development of the single-degree-of-freedom integrating rate gyroscope

This event involved the invention, development and laboratory demonstration of the floated single-degree-of-freedom integrating rate gyroscope as a superior inertial sensor of angular motion.

1946-48	MIT Instrumentation Lab.	Sergeant, Hound Dog, Polaris

No. 53 (AD) Gallagher

Adaptation of pressure sensing device for use as engine power control

This event consisted of the use of a standard safety device to provide throttle control in a missile engine.

1958-58 NAA Hound Dog

No. 54 (AD or possibly XD) Heuchling

*Development of digital differential analyzer for aircraft navigation

This event consisted of the development of a digital differential analyzer having particular features of logical design, machine organization, and input-output facilities to suit it for use in an aircraft navigator.

1953-57 NAA Autonetics Div. Hound Dog, Polaris, Minuteman

No. 58 (AD) Gallagher

Development of the variable-position inlet diffuser

This event involved the development of a conical-shock (or "spike") type of engine inlet diffuser suitable for use at both subsonic and supersonic velocities, and marked the successful embodiment of principles set forth by Ostwatisch and Ferri in the late 40's and early 50's.

1957-58 NAA Hound Dog

No. 59 (XD) Gallagher

*Development of fuel antifreeze

This event consisted of the search for a material that would prevent icing in JP-4 fuel.

1959-59 Phillips Petroleum Hound Dog

No. 60 (XD) Gallagher

*Development of a reliable low-altitude radar altimeter

This event consisted of the development of a radar altimeter circuit that allowed highly reliable operation at low altitude in a jet-engine environment.

1955-57 Emerson Hound Dog

No. 61 (XD) Heuchling

*Development of the magnetic suspension to replace jewel bearings on the gimbal axis of precise gyros

This event concerns the discovery, analysis, parametric description, and development of an electronically simple, electromagnetic radial and thrust bearing to support the gimbal of a single-degree-of-freedom gyroscope, and thereby, to reduce further the gyro drift which is caused by small uncertainty torques in the gimbal bearings.

1953-59	MIT Instrumentation Lab.	Polaris

No. 62 (XD) Heuchling

*Development of guidance concept based upon computation and control of velocity to be gained

This event involves the conception, formulation, preliminary design and analytical evaluation of an improved inertial guidance system for ballistic missiles.

1953-55	MIT Instrumentation Lab.	Polaris

No. 63 (XD) Heuchling

*Development of hydrodynamically generated gas journal and thrust bearings for gyros

This event concerns the development and application of hydrodynamically generated gas journal and thrust bearings for the gyro wheel of single-degree-of-freedom gyroscopes.

1954-56	NAA	Polaris

No. 65 (XD) Stuart

Development of missile thrust control method

This RXD event consisted of the development of an uncomplicated and readily actuated but positive thrust control method for the Sergeant missile solid propellant rocket motor.

1956-59	JPL	Sergeant

No. 66 (XD) Stuart

Development of zero length nonvertical missile launch

This RXD event consisted of the conception of an unconstrained, nonvertical launch for a missile of substantial size, and the experimental and analytical exploratory investigation required to determine a reasonably proportioned system and demonstrate its feasibility.

1957-59	JPL	Sergeant

No. 71 (R)
Rudenberg

*Development of epitaxial deposition of semiconductor material

This event consists of the development of a method of adding a thin layer of single crystal semiconducting material to the surface of a single crystal wafer.

1950-60 BTL Minuteman

No. 75 (XD)
Stuart

Development of propellant additives to inhibit gun tube erosion

This event consisted of a systematic evaluation of potential propellant additives in relation to gun tube erosion, and resulted in the identification of a class of metallic oxides as useful inhibitors.

1954-58 Swedish government Howitzer

No. 78 (XD)
Stuart

Development of autofrettage swaging

This RXD event consists of the development of a new means for increasing the effective bursting strength of artillery gun tubes.

1956-59 Watervliet Arsenal Howitzer

No. 80

*Classified

No. 81 (XD)
Sykes,
Mazuy

*Development of Revel Panel, transit time alignment compensation

This event consisted of the development of a method for compensating for the loss in sensitivity of an active acoustic torpedo during the circling search mode by shifting the transmitting beam to lead the receiving beam axis.

1956-58 NOTS Mark 46

No. 82 (XD)
Sykes,
Mazuy

*Development of Revel Panel, reverberation filtration

This event consisted of the measurement of the levels of reverberation that might be experienced by an active acoustic torpedo and the development of a suitable filter system for increasing the signal-to-reverberation ratio of the Mark 46-0 torpedo acoustic homing system.

1956-58 NOTS Mark 46

No. 83 (XD) Sykes, Mazuy

*Development of Revel Panel, recognition of noise-limited and reverberation-limited conditions

This event consisted of the development of a method for continuously recognizing whether an active acoustic homing torpedo was self-noise or reverberation-limited and for selecting the target detection method suitable for the prevailing condition.

1956-58 NOTS Mark 46

No. 84 (XD) Sykes, Mazuy

*Development of Revel Panel, bilateral automatic gain control

This event consisted of the recognition of the fact that the reverberation level for active acoustic torpedoes was not always an exponential decay curve, and the design of a suitable gain control system.

1958-59 NOTS Mark 46

No. 86 (XD) Klein

*The design and demonstration of a low-cavitation propellor

This event consists of the design and demonstration of a high-speed, low cavitation-noise propellor.

1954-55 Penn. State U/ ORL Mark 46

No. 87 (XD) Klein

Development of rational design criteria for counter-rotational propellors

This event consisted of the examination of the theory of counter-rotational propellors and the development of rational design procedure.

1955-59 DTMB Mark 46

No. 88 (XD) Klein

*Development of hot-gas engine

This event consisted of the development of a swash-plate engine to be operated from hot gas generated by a monofuel.

1953-56 Clevite Mark 46

No. 92 (XD) Klein

*Development of an effective and reliable influence fuze for acoustic torpedoes

This event consisted of the development of a short-range influence fuze for achieving the reliable detonation of acoustic homing torpedoes.

1954-55 APL/U. of Wash. Mark 46

No. 93 (XD) Raisbeck — *Formulation of H-6 explosive

This event consisted of the systematic experimental study of a family of high-explosive mixtures to find the mixture having the optimal air blast consistent with castability and safety requirements.

1950-51	NOL	Mark 46

No. 94 (XD) Raisbeck — *Optimization of RXD/TNT/Al mixture for maximum underwater shock energy

This event consisted of systematic experimental measurement of the underwater blast parameters of a family of high-explosive mixtures.

1950-52	NOL	Mark 46

No. 95 (XD) Raisbeck — Determination of most desirable compromise among shock and bubble energies for an underwater explosive

This event consisted of systematic theoretical and experimental studies of the relation between underwater explosive parameters and damage.

1950-57	NOL-DTMB	Mark 46

No. 96 (XD) Heuchling — Conception of the 84-minute pendulum to prevent vehicle horizontal accelerations from causing spurious precession of a gyrocompass.

This event involves the conception, analytical justification, and proposed mechanization of a means of preventing a marine gyrocompass from experiencing transient disturbances in response to horizontal accelerations of the sort which arise during a change in ship's course.

1906-23	Anschutz	Hound Dog, Polaris

No. 97 (AD) Heuchling — Development of an improved Marine Stable Element (MAST) utilizing post-World War II inertial component and system ideas

This event concerns the application of a recently developed single-degree-of-freedom integrating rate gyroscope (RXD Event No. 52), and the platform stabilization and north- and vertical-tracking features under development for the Air Force (RXD Event No. 41), to the Navy's long standing problem of providing a set of stabilized reference coordinates for use in gun-laying aboard ship.

1948-54	BuOrd	Hound Dog, Polaris

No. 98 (AD) Heuchling

Development of a ship's inertial navigation system (SINS)

This event concerns the conception, development and sea tests of the first experimental inertial navigation system for shipboard and submarine end use.

1950-1955	MIT Instrumentation Lab.	Polaris

No. 99 (AD) Heuchling

Development and flight test of the first all-inertial aircraft navigation systems, SPIRE (Space, Inertial Reference Equipment)

This event concerns the conceptual design, development and flight test of the first all-inertial aircraft navigation system.

1949-53	MIT Instrumentation Lab.	Polaris, Hound Dog

No. 101 (I & XD) Rudenberg

*Development of planar transistor process technology

This event consists of the invention and exploratory development of a process for making silicon transistors using photolithography and diffusion, simpler and cheaper than earlier methods, which led to transistors of extremely high reliability.

1957-58	Fairchild	Polaris, Minuteman, Sergeant

No. 103 (AD or possibly XD) Heuchling

*Development of the Cytac long-range, precise, hyperbolic radio navigation system

This event involved the conception, analysis, construction and feasibility demonstration of a low-frequency, long-range, precise, hyperbolic radio navigation system employing both envelope and carrier-phase matching for timing measurements.

1953-54	Sperry	Polaris

No. 106 (R) Rudenberg

*Research on a solid-state amplifier (transistor)

This event consisted of research on solid-state physics to obtain new knowledge of the functional properties of semiconducting materials, which might be used in the development of completely new and improved components of communication systems and which led to the discovery of the transistor.

1945-48	BTL	Polaris, Minuteman, Sergeant, Hound Dog

No. 107 (R) Rudenberg

*Conception of transistor with bonded, alloyed contacts

This event consisted of the conception and demonstration of methods of constructing transistors with bonded or alloyed contracts having properties resembling those of point-contact or junction transistors.

1948-48	BTL	Sergeant, Polaris, Minuteman, Hound Dog

No. 108 (R) Rudenberg

*Development of method for growing high-purity single crystals of germanium

This event consisted of the study of imperfections arising in crystal-growing, and the selection and adaptation of a method of crystal-growing to the point of producing large pure single crystals of germanium and silicons.

1948-50	BTL	Hound Dog, Polaris Minuteman, Sergeant

No. 109 (XD) Rudenberg

*Development of a germanium transistor with alloyed indium junctions

This event consists of the development of a technique for the preparation of a junction transistor without resorting to multiple doping during crystal growing.

1951-51	GE	Hound Dog, Polaris, Sergeant

No. 110 (R) Rudenberg

*Demonstration of zone melting for purification of metals

This event consists of the discovery and demonstration of a new, highly efficient method of fractional crystallization of materials, called zone melting or purification, where short transverse molten zones of the metal are caused to move gradually through the length of a solid metal ingot bar, thereby sweeping most of the impurities toward one end.

1950-51	BTL	Hound Dog, Minuteman Polaris, Sergeant

No. 111 (R) Rudenberg

*Development of high-frequency PNIP transistors

This event consists of the analysis of the limitations of high-frequency transistors and their reduction through the incorporation of an additional, thin high-resistivity layer on the collector side of a junction transistor.

1952-53	BTL	Hound Dog, Minuteman, Polaris, Sergeant

No. 112 (XD) Rudenberg

Development of silicon transistor

This event consists of the development of a silicon transistor.

1953-54	Texas Instruments	Minuteman, Polaris. Sergeant, Hound Dog

No. 113 (I & XD) Rudenberg

Development of an oxide masking process for delineating diffusion regions on silicon transistors

This event consisted of the development of a method of laterally delineating areas on a silicon wafer for the diffusion of impurities, thus providing simple patterns of doped semiconductor regions to act as emitter or base areas in a transistor.

1954-55	BTL	Minuteman, Polaris, Sergeant

No. 114 (R) Rudenberg

Research on diffusion techniques for transistors

This event consisted of research on diffusion techniques in semiconductor material suitable for transistors, particularly silicon or germanium, which would avoid the undesirable side effects encountered in earlier applications to transistor and junction fabrication.

1950-56	BTL	Minuteman, Polaris, Sergeant

No. 115 (R) Rudenberg

Development of thermo-compression bonding for transistors

This event consists of the development of a method of making reliable contact to the small islands of metallized patterns on a single crystal wafer of silicon, without applying deleteriously high pressures or temperatures to the wafer.

1954-56	BTL	Minuteman, Polaris

No. 116 (I & XD) Rudenberg

Development of method for levitation of a floating zone of silicon

This event consists of the invention and development of a method of generating a stable layer of molten silicon material between the ends of two short silicon crystals arranged coaxially, without having the molten zone in contact with a crucible.

1952-53	US Signal Corps	Minuteman

No. 117
(XD)
Rudenberg

*Development of molecular electronics amplifiers

This event consists of the development of an integrated circuit based on "molecular electronics," exploring the capabilities of germanium and silicon structures and fabrication processes to produce useful linear or analog functional circuits on one block of semiconductor material.

1958-61	Westinghouse	Minuteman

No. 118
(I & XD)
Rudenberg

*Conception and demonstration of "molecular electronic" integrated circuits

This event consisted of the implementation of so-called molecular electronic concepts by actual functional electronic blocks, in this case on oscillator controlled in frequency by light or heat, built entirely on one piece of semiconductor material.

1957-58	Westinghouse	Minuteman

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APPENDIX D

STANDARD ENVIRONMENT QUESTIONS

It should be understood at the outset that the environment in which an R&D event was performed cannot be ascertained by means of a questionnaire. Nor can a standard set of questions be utilized, because the real environment information comes out only in an informal type of interview during which good rapport is established.

The only use which can be made of a set of questions is simply to remind one of the ground which should be covered. How one phrases the questions is quite dependent upon the type of person being interviewed and the conditions surrounding the interview.

In performing technical audits we have found that it is usually more productive if two ADL people interview a man as this makes it easier to keep the questions flowing, and permits our staff members to compare and discuss their reactions subsequent to the interview.

In analyzing the results of our environment studies it might be of some interest to look at the answers to groups of questions. There may be a core of things which are usually found in a successful R & D environment.

The following set of questions is not presented as being complete, but as a starter. A particular effort has been made to word the questions so that the answers can be terse. One penalty is that the answers may be redundant (e.g., 1e, 2f, 3c). Another penalty is that some questions may fail to apply (e.g., 5c).

1. Timing

a. When did the RXD Event begin and end?

b. Was the Event part of a steady sequence from research, to exploratory development, to advanced development, to engineering development, etc., with clear transitions and no gaps in time or character of the work? (If no, explain.)

c. When was the initiation of the weapon system development in which this RXD Event was utilized?

d. Would the state of scientific and technical knowledge, instrumentation, etc., have allowed this work to be done earlier?

e. (Cf. 3c) If perception of a military need, mission, or system problem was a stimulus to this Event, what was the delay (if any) between the stimulus and the initiation of the Event?

2. Personnel

a. Who conceived the idea? Was this the same person who launched the work?

b. Was formal approval required before work could begin? If so, by whom? If not, whose acquiescence or informal approval was required?

c. What was the administrative delay, if any, in getting the work started? Did our correspondents report any earlier proposals to do the same work?

d. Who worked on the RXD Event, and what were their backgrounds and reputations?

e. (Cf. 3d, 3e, and 4h) Was there any professional stimulation from others inside or outside the organization, in particular, anyone from DOD? If so, from whom?

f. (Cf. 3c) If a military need, mission, or system problem motivated this RXD Event, who got and sold the initial concept as a response suitable to the stimulus?

g. (Cf. 3c, 1e) Did our respondents report any particular difficulties in selling the idea for this application?

3. Motivation

a. Why and how did the persons responsible for the idea get the idea?

b. Did they have a background of association with DOD activities?

c. Was the idea entirely separate from any military need; or was it need, mission, or systems oriented?

d. What degree of urgency (with respect to both time and importance) was reported? Was any competition reported? Do our respondents report the establishment of any formal priorities? If so, who established them?

e. (Cf. 4g and h) What degree of encouragement or opposition to this activity was reported? (Cf. 4g and h) Did it come from within or outside of the organization?

4. Atmosphere (If a group smaller than the whole institution can be identified as the locus of the Event, answer a, b, e and d for this group also)

a. What laboratory was involved?

b. What general reputation did the laboratory enjoy? What were its strong and weak points? Had it enjoyed this reputation for some time before the Event? Did it continue to enjoy this reputation for some time after the Event?

c. What were its size and age?

d. (Cf. 6e) What was its reputation in the particular field of the RXD Event?

e. Who was the laboratory director, and what was his reputation.

f. (Cf. lc) Did the laboratory director or anyone else outside the group play a significant role as intermediary between the idea man or group and the sponsors or users of the RXD? If so, explain.

g. Was the management of the group authoritarian or adaptive? (See WM# 16.)

h. Were the relations between the group and its sponsors based on consensus-collaboration or coercion-compromise? (See WM# 16.)

i. Do our respondents report any indications of unusually low or high morale?

j. Were any special circumstances reported which inhibited or helped this RXD Event?

5. Financing

a. Were the earliest stages of this work funded from government or non-government funds? Was the funding from sources designated specifically for this task, from sources generally set aside for discretionary commitment to work of this character (including institutional funding), or diverted from funds ordinarily commited to other work (including allowable overhead and bootleg)?

b. (Cf. 4g) If any part of the funding required formal approval, how long was it before this approval was granted? If there was any delay, was the work interrupted or was it informally supported in the interim?

c. Who granted the formal approval?

d. Was there funding by another agency after the initial funding? (Omit if answered in 5b.)

e. If the ultimate source of the initial funding was the Defense Department, did its source correspond to 6.1, 6.2, 6.3 ....6.7?

f. Were any exceptional relationships between the idea people or the director and the DOD people having authority to spend money reported?

g. (Cf. 6a, 2e) Was any unusual degree of harmony or conflict between the DOD project officer and the contracting officer reported? If so, were any particular problems or benefits reported in consequence of this?

h. What was the cost of the RXD Event?

6. The Idea

a. (Cf. 1b, 3c) Was this RXD Event the logical outgrowth of more basic work preceding it?

b. Who did this more basic work?

c. Did this RXD work lead to papers, patents, or reports?

d. (Cf. 3d and 3e) Were the merits of the idea sufficiently vivid at an early stage to attract support -- to attract good people from outside the "starter" group?

e. In what field of science or technology does this RXD Event fall?

f. How mature was this field of science or technology? What was the relative experience or reputation of the protagonists in this field? Did they enjoy a higher reputation or have more experience in another field?

g. Was this a field in which the DOD was supporting work? If so, did the support extend to work aimed at the same mission as this Event?

7. Transition (The purpose of questions under this heading is to try to find out how the RXD Event came to be used in a weapons system. Often in the past it has been difficult to sell the military on the potential value of a finding.)

a. How was the RXD progressed through to a completed development for use in a weapons system?

b. What were the major problems involved (money, channels, priorities, competition, etc.)?

c. Who was the "salesman" for the use of the idea?

d. Who was the military man who had to be sold? Did this individual keep changing?

e. Were the military requirements clear?

f. Who formulated them and in what sort of a document (GOR, ADO, RFQ, etc.)?

8. SORXDM

a. What measures to improve the environment for RXD were suggested by our respondents?

b. What particular ideas, if any, did our respondents suggest which might add to the substance of our report?

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APPENDIX E

SPECIFIC ENVIRONMENTAL QUESTIONS

A. INTRODUCTION

The following list of questions was formulated during the reduction of the data, to assist in drawing specific comparisons. These questions were not put to our respondents, but were answered by our interviewers after interviews had been completed. They reflect the judgment of the interviewer, and may be based on information from several sources.

Because of the small size of the sample and the coarseness of a forced answer to multiple choice questions, we do not regard any single total or distribution as significant. However, the qualified statements about trends and distribution in the Discussion can be referred to these data if desired.

Each question is accompanied by its code and the frequency of answers. Table E-1 displays all the data in matrix form. Each row represents one RXD Event, each column one question. The rows are randomly scrambled to protect the confidences of our respondents. Table E-2 shows the frequency of answers, as sorted by a computer.

Strategy

	Code	Frequency 11 R	52 XD	63 RXD
1. Cost Effectiveness (Col. 30)*				
At the time this Event was initiated, a reasonable estimate of its potential value times its probability of success would have exceeded a reasonable prediction of the cost of the Event by 10^{-1}, 10^{0}, 10^{1}, 10^{2}, etc:	10^{-2} 8	-	-	-
	10^{-1} 9	1	1	2
	10^{0} 0	2	2	4
	10^{1} 1	2	28	30
	10^{2} 2	6	19	25
	10^{3} 3	-	2	2
	10^{4} 4	-	-	-
2. Risk Strategies (Col. 31)				
No strategy of technological speculation by DOD is visible in the circumstances surrounding the decision to fund this work:	False.............0	-	33	33
	True 1	8	18	26
	Other 2	3	1	4
3. The following strategy was observed:				
Invest in Fields (Col. 71)				
Invest in fields of research and development characterized by obvious continuing interest in weapons technology, and/or a rapid rate of change in the state of scientific understanding and technological exploitation, and/or a clear current need for improvements:	False.............0	11	35	46
	True 1	-	17	17
	Other			
Invest in Research (Col. 72)				
Invest in research and development institutions characterized by a record of accomplishment, and/or facilities well matched to the work to be done, and/or access to university resources, and/or an objective approach to alternate solutions, and/or having a director whose dynamism inspires confidence:	False.............0	11	47	58
	True 1	-	5	5
	Other			
Invest in Men (Col. 73)				
Invest in men of distinguished accomplishment in the field of interest:	False.............0	11	49	60
	True 1	-	3	3
	Other			

*The designation Col. 30, etc., refers to the location of the data on the input card and unprocessed data printout. It is of no concern to the reader, but is retained as an aid to the authors' verification that the data are accurate.

Invest in Evaluation Work (Col. 74)

When the need is clear support evaluation work on all ideas which show even remote promise of meeting the need:	False.............0	11	47	58
	True 1	-	5	5
	Other			

Allocate Discretionary Fund (Col. 75)

Allocate some discretionary funds to a large class of research and development institutions, recognizing that creative ideas occur at random, that broad awareness of military needs will promote productivity, and that the capability promptly to evaluate randomly occurring ideas is desirable:	False.............0	11	50	61
	True 1	-	2	2
	Other			

Force by W/S Development (Col. 76)

Force technological progress by attempting to develop a weapon system even though advances in a number of areas will be essential to success:	False.............0	11	48	59
	True 1	-	4	4
	Other			

Force by Requirements (Col. 77)

Focus research and development effort by clear statements of weapon system performance requirements, but let technological advances pace system development effort:	False.............0	11	49	60
	True 1	-	3	3
	Other			

4. Clear Transition (Col. 19)

Transitions in Stages of Development - The changes in the character of activity corresponding to the transition R to XD or XD to AD were not clear (including transitions at beginning and end of Event):	False.............0	1	22	23
	True 1	10	30	40

5. Progress Irregularity (Col. 12)

This activity derived some essential idea, or stimulus, or information from a less basic development activity (i.e., from AD, ED, OSD, T or E) Answer F only if all ideas, resources, and stimulation resulted from non-technical considerations and from previous R and (in the case of XD) previous XD):	False.............0	3	19	22
	True 1	8	33	41

Initiation of an RXD Event

6. Three Elements Essential to RXD (Col. 1)

When this RXD Event was initiated, the following three were elements present: an explicitly understood need, goal, or mission; resources (facilities, money, materials, men) which could be committed promptly; a source of ideas (experienced, imaginative men).	True 1	10	49	59
If false, the following were missing:	Missing need 2	1	3	4

7. Element which Triggered Event (Col. 26)

The element which triggered this Event was:	Need 1	2	16	18
	Idea 2	6	22	28
	Resource Allocation 3	3	14	17
	Other			-

8. Trigger Delay Time (Col. 27)

Triggering occurred after the other two elements had been joined for _____ years:	0 years 0	2	19	21
	1 year 1	6	5	11
	2 years 2	1	10	11
	3 years 3	2	6	8
	4 years 4	-	6	6
	5 years 5	-	2	2
	6 years 6	-	1	1
	7 years 7	-	-	-
	8 years 8	-	-	-
	9 or more years....9	-	3	3

9. State-of-the-Art Delay in Years (Col. 28)

An adequate scientific and technological base for this event had existed for _______ years before the Event was initiated; i.e., this innovation + technology which has been around for _______ years = Event.	0 years 0	-	4	4
	1 year 1	1	2	3
	2 years 2	4	10	14
	3 years 3	1	5	6
	4 years 4	-	4	4
	5 years 5	-	6	6
	6 years 6	1	1	2
	7 years 7	1	-	1
	8 years 8	-	4	4
	9 or more years 9	3	16	19

10. Locus (Col. 6)

The initial activity was done at the place where:	The idea was generated 1	10	47	57
	The need was expressed 2	-	3	3
	At neither place ...0	1	1	2
	Where both idea was generated and need felt...............3	-	1	1

11. Specific Need (Col. 3)

Two levels of need were recognized, a general need expressed earlier and a more specific need expressed later, and the RXD Event was stimulated:	By the later more specific need 1	5	25	30
	By the more general need..............0	-	2	2
	Other, including no need or only one level of need expressed...........2	6	25	31

Initial Funding

12. Work Was Started Promptly (Col. 2)

Work was started promptly after need and idea were brought together:	False.............0	1	9	10
	True 1	10	43	53

13. DOD or Private Fund (Col. 21)

The funds which supported the initiation of this RXD Event were ultimately:	From the DOD 1	3	38	41
	From private sources 2	8	14	22
	Other 3	-	-	-

14. Type of Fund (Col. 22)

The initial stages of work were funded out of funds:	Available for discretionary expenditure 1	-	7	7
	For the support of related work, but in which the particular RXD Event was not specified or anticipated 2	8	28	36

14. Type of Fund (Col. 22) (Cont.)

	Borrowed from other activities 3	1	6	7
	Specifically set aside for this activity (possibly as one of many) before initiation 4	-	5	5
	Specifically approved for this work after the idea was generated..5	2	6	8
	(Source of initial funding doubtful)....6	-	-	-

15. Local Decision (Col. 55)

The decision to give initial financial support to this work was made locally:	False..............0	2	10	12
	True 1	9	41	50
	Other 2	-	1	1

C. EXECUTION OF RESEARCH AND EXPLORATORY DEVELOPMENT

RXD Flourishes in an Adaptively Organized Group

16. Adaptive Environment (Col. 7)

The local environment in which the RXD Event was carried out was adaptive rather than authoritarian:	False (author.)......0	-	1	1
	True (adapt.) 1	11	51	62
	Neither or NA 2	-	-	-

17. Adaptiveness was introduced and sustained in the situation by:

Philosophic commitment to adaptiveness (Col. 43)

A philosophic commitment to adaptiveness on the part of laboratory management;	False..............0	-	29	29
	True 1	11	23	34

Supergoals (Col. 44)

The influence of goals whose importance transcended all other considerations;	False..............0	8	40	48
	True 1	3	11	14
	Other..............2	-	1	1

A dominant adaptive personality (Col. 45)

A dominant adaptive personality;	False..............0	8	41	49
	True 1	3	11	14

Rapid size change (Col. 46)				
A rapid growth in the size of the organization, with enhanced fludity;	False.............0	9	39	48
	True 1	2	13	15
Mission change (Col. 47)				
A change of mission;	False.............0	11	50	61
	True 1	-	2	2
Organization by tasks or projects (Col. 48)				
Laboratory organization by tasks or projects; and/or	False.............0	11	30	41
	True 1	-	22	22
Competition to survive (Col. 49)				
A competitive drive which transcended all other considerations.	False.............0	11	41	52
	True 1	-	11	11
The environment was not adaptive (Col. 50)	False.............0	11	51	62
	True 1	-	1	1
18. Significance of Competition (Col. 16)				
The desire to show the superiority of technical approach (or capability) over conventional approaches or those being worked on elsewhere appeared to contribute positively to success or effectiveness. (Other if no competition; F if competition produced an adverse effect):	False.............0	-	3	3
	True 1	10	35	45
	Other.............2	1	14	15
19. Adaptive Control Present (Col. 18)				
The controls appropriate to an adaptive system were present. (If external evidence is gathered, past performance examined, and purposeful decisions made according to values and standards appropriate to goals, these constitute valid adaptive controls.):	False.............0	-	3	3
	True 1	11	49	60
	Other.............2	-	-	-
20. Within Authoritarian Organization (Col. 8)				
The RXD was done in an adaptive subunit of a larger basically authoritarian organization (e.g., "loosely" supervised R&D group, a group operating "not according to standard practices," etc.) (other = parent organization not authoritarian):	False.............0	-	1	1
	True 1	-	7	7
	Other.............2	11	44	55

21. Importance of Commitment (Col. 15)

There is evidence that personal enthusiasm, dedication, and commitment to the achievement of goals were present in those working on the RXD Event and that it contributed to success or effectiveness:	False.............0	-	5	5
	True 1	11	47	58

22. Adaptive Decreases (Col. 14)

The degree of adaptiveness of this organization decreased steadily with time:	False.............0	11	22	33
	True 1	-	21	21
	Other.............2	-	9	9

RXD Flourishes When the Group Enjoys Consensus-Collaboration Relations With its Sponsors

23. Consensus-Collaboration (Col. 10)

The relation between the group doing the RXD and their sponsors (prime contractor if sub, parent organization, if a separate lab, contracting office if a DOD contractor, etc.) was a consensus-collaboration relation:	True 1	11	38	49
(If the first statement is False) There was a significant informal communication channel supplementing or replacing a direct channel to the sponsor:	False.............0	-	3	3
	True 2	-	10	10
	Other.............3	-	1	1

24. The basis of the consensus-collaboration relationship between sponsors and protagonists in this case was--(not mutually exclusive).

Long personal association (Col. 37)	False.............0	8	31	39
	True 1	3	21	24
Strong technical insight at both ends of link (Col. 38)	False.............0	3	38	41
	True 1	8	14	22
Attention focused on goals (Col. 39)	False.............0	7	33	40
	True 1	4	19	23

A single superpersuasive personality (Col. 41)	False.............0	11	44	55
	True 1	-	8	8
(Col. 42)	Other bases absent.0	10	39	49
	Other bases present..............1	1	1	2
	Not consensus-collaboration......2	-	12	12
25. Informal Exp. (Col. 4)				
The understanding of the need was passed on informally, rather than exclusively by a formal document (RFP, SOR, etc.)	False.............0	2	2	4
	True 1	8	46	54
	Other.............2	1	4	5
26. Sponsor Conception (Col. 29)				
This Event was not conceived by its sponsors and promulgated in an RFP, GOR, etc.:	False.............0	-	4	4
	True 1	3	40	43
	Other.............	8	8	16
27. Promoter-Conceiver Relationship (Col. 34)				
The promoter of initial support for this work was closely identified with the conceiver(s) of the ideas:	False.............0	-	14	14
	True 1	11	37	48
	Other.............2	-	1	1
28. Resistance to Innovation (Col. 11)				
Some program for carrying out this RXD Event or its substantial equivalent was turned down, passed over, ignored, or refused funds, by DOD at or before the time the Event was done:	False.............0	6	30	36
	True 1	2	16	18
	Other.............2	3	6	9
29. DOD Author (Col. 13)				
This RXD Event shows evidence that the DOD acted in the way expected of:	an adaptive organization........0	1	17	18
	an authoritarian organization........1	2	17	19
	(ambiguous, equivocal, or not observed).........2	8	18	26

30. Laboratory Director (Col. 20)

The reputation of the laboratory director was:	Fair, poor, no infor. or NA 2	-	16	16
	Good 3	-	11	11
	Excellent 4	11	25	36

31. R&D Reputation of Group (Col. 35)

At the time this work was done, the organization in which it was done either already had or was rapidly developing a reputation as a first-rate development activity:	False.............0	1	8	9
	True 1	10	43	53
	Other.............2	-	1	1

32. Outstanding Contributor Reputation (Col. 33)

No principal contributor to this Event was professionally distinguished at the time the Event occurred:	False.............0	10	21	31
	True 1	1	30	31
	Other.............2	-	1	1

33. Conceivers Involved in Execution (Col. 51)

Conceivers remained involved in the execution of this RXD:	False.............0	1	6	7
	True 1	10	45	55
	Other.............2	-	1	1

34. Exceptional Personnel (Col. 17)

The behavior of some creative and imaginative individual(s) involved in this RXD Event was seen as outside the range normal to the organization ("mad scientist," "odd-ball," etc.):	False.............0	10	45	55
	True 1	1	7	8

Field of Work

35. State-of-the-Art Change (Col. 32)

The field in which this Event occurred was not changing rapidly at the time this Event was initiated:	False.............0	7	36	43
	True 1	4	13	17
	Other.............2	-	3	3

36. Interdisciplinary Stimulation (Col. 36)

Interdisciplinary stimulation within this organization was important in the conception and execution of the idea:	False.............0	1	22	23
	True 1	10	29	39
	Other.............2	-	1	1

D. UTILIZATION OF RESEARCH AND EXPLORATORY DEVELOPMENT

37. Delay after Completion (Col. 52)

A delay of ______ years occurred between the completion of this RXD and its incorporation in system development:

0 years 0	3	20	23
1 year 1	1	9	10
2 years 2	1	7	8
3 years 3	-	7	7
4 years 4	-	3	3
5 years 5	2	2	4
6 years 6	1	-	1
7 years 7	1	3	4
8 years 8	2	-	2
9 or more years . . .9	-	1	1

38. Paper Bridge (Col. 53)

Papers, patents and reports were not an important mechanism in bringing about first utilization of the RXD:

False. 0	11	18	29
True 1	-	33	33
Other. 2	-	1	1

39. Human Bridge (Col. 54)

The personnel bridge (salesman) to utilization of this RXD was closely identified with either the conception or the execution of this RXD, or both:

False. 0	-	9	9
True 1	11	42	53
Other. 2	-	1	1

40. Timing (Col. 23-24)

How many years before (or after) the initiation of system development was this RXD Event undertaken:

3 years after 96	-	1	1
2 years after 97	-	2	2
1 year after 98	-	4	4
0 year after 99	-	4	4
0 year before. 00	1	8	9
1 year before. 01	1	5	6
2 years before. . . .02	2	4	6
3 years before. . . .03	-	7	7
4 years before. . . .04	1	7	8
5 years before. . . .05	1	4	5
6 years before. . . .06	-	-	-
7 years before. . . .07	3	1	4
8 years before. . . .08	1	3	4
9 years before. . . .09	-	2	2
10 years before. . . .10	1	-	1
11 years before. . . .11	-	-	-
12 years before. . . .12	-	-	-

TABLE E-1 ANSWERS TO SPEC O S

Events	COST EFFECTIVENESS 30	RISK STRATEGY 31	INVEST IN FIELDS 71	INVEST IN LABORATORIES 72	INVEST IN MEN 73	INVEST IN EVALUATION WORK 74	ALLOCATE DISCRETIONARY FUNDS 75	FORCE BY W/S DEVELOPMENT 76	FORCE BY REQUIREMENTS 77	CLEAR TRANSITION 19	PROGRESS IRREGULARITY 12	THREE ELEMENTS ESSENTIAL TO RXD 01	ELEMENT WHICH TRIGGERED EVENT 26	TRIGGER DELAY TIME 27	STATE OF ART DELAY IN YEARS 28	LOCUS 06	SPECIFIC NEED 03	WORK WAS STARTED PROMPTLY 02	D.O.D. OR PRIVATE FUND 21	(TYPE OF FUND) 22	LOCAL DECISION 55	ADAPTIVE ENVIRONMENT 07	PHILOSOPHIC COMMITMENT TO ADAPT 43	SUPER GOALS 44	DOMINANT ADAPTIVE P 45	RAPID SIZE CH 46	MISSION 47	OR 48	RAPID 47
																													0
11 R Events	2	1	0	0	0	0	0	0	0	0	0	2	2	1	9	1	2	1	1	2	0	1	1	1	1	0	0	0	0
	2	1	0	0	0	0	0	0	0	1	0	1	3	1	2	0	1	0	1	5	0	1	1	1	1	1	0	0	0
	2	2	0	0	0	0	0	0	0	1	1	1	2	0	7	1	1	1	2	2	1	1	1	0	0	0	0	0	0
	0	2	0	0	0	0	0	0	0	1	1	1	2	1	9	1	2	1	2	3	1	1	1	0	0	0	0	0	0
	9	1	0	0	0	0	0	0	0	1	1	1	2	0	2	1	2	1	2	2	1	1	1	0	0	0	0	0	0
	2	1	0	0	0	0	0	0	0	1	1	1	2	3	9	1	2	1	2	2	1	1	1	0	0	0	0	0	0
	1	1	0	0	0	0	0	0	0	1	1	1	1	2	2	1	1	1	2	2	1	1	1	0	0	0	0	0	0
	2	2	0	0	0	0	0	0	0	1	0	1	3	1	6	1	2	1	2	5	1	1	1	0	0	0	0	0	0
	1	1	0	0	0	0	0	0	0	1	1	1	2	1	1	1	1	1	2	2	1	1	1	0	0	0	0	0	0
	0	1	0	0	0	0	0	0	0	1	1	1	1	3	3	1	2	1	2	2	1	1	1	0	0	0	0	0	0
	2	1	0	0	0	0	0	0	0	1	1	1	3	1	2	1	1	1	1	2	1	1	1	1	1	1	0	0	0
52 XD Events	2	0	1	0	0	0	0	0	0	0	1	1	2	4	0	1	2	1	1	2	1	1	1	1	0	0	0	0	0
	2	0	1	1	0	0	0	0	0	0	1	1	2	4	4	1	2	1	1	2	1	1	1	0	0	0	0	0	0
	2	1	0	0	0	0	0	0	0	0	1	1	3	0	9	1	2	1	1	2	1	1	0	1	0	0	0	0	0
	1	0	1	0	0	0	0	0	0	0	1	1	2	5	3	1	2	1	1	2	1	1	1	0	0	0	0	0	0
	2	0	1	0	0	0	0	0	0	0	1	1	2	9	0	1	1	1	1	2	1	1	1	0	0	0	0	0	0
	2	0	0	0	0	1	0	0	0	0	0	1	3	9	4	0	2	1	1	2	0	1	0	0	1	0	0	0	0
	1	0	1	0	0	0	0	0	0	0	1	1	2	2	9	1	1	1	1	2	1	1	1	0	0	0	0	0	0
	1	0	1	0	0	0	0	0	0	0	1	1	1	3	9	2	2	1	1	2	1	1	1	0	0	0	0	0	0
	1	0	1	0	0	0	0	0	0	0	1	1	2	3	9	1	2	1	1	2	1	1	1	0	0	0	0	0	0
	2	1	0	0	0	0	0	0	0	0	1	1	3	2	2	1	1	1	2	2	1	1	0	0	0	0	0	1	0
	1	0	0	0	0	0	1	0	0	0	1	1	1	1	9	1	1	1	1	1	1	1	1	1	0	0	0	0	0
	1	0	0	0	0	0	0	1	0	1	1	1	3	4	4	1	1	1	1	2	0	1	0	1	0	0	0	1	0
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	2	1	0	0	0	0	0	0	0	1	1	1	2	3	2	1	1	1	2	1	1	1	0	0	1	0	0	0	0
	2	1	0	0	0	0	0	0	0	1	1	1	3	1	2	1	1	1	1	2	1	1	1	1	1	1	0	0	0
	1	0	0	0	0	0	0	0	0	1	1	1	1	0	9	3	0	1	1	2	1	1	0	0	0	1	0	0	1
	2	0	0	0	0	1	0	0	0	1	1	1	1	0	5	1	2	0	1	4	0	1	0	1	0	0	1	0	1
	3	0	0	0	0	1	0	0	0	1	1	1	2	0	5	1	2	1	1	2	1	1	0	1	0	0	1	0	0
	1	1	0	0	0	0	0	0	0	0	0	2	2	0	9	1	2	1	2	1	1	1	1	0	0	0	0	0	0
	1	1	0	0	0	0	0	0	0	0	1	1	3	4	9	1	1	0	1	4	0	1	0	0	0	1	0	1	0
	2	0	0	0	0	0	0	1	0	0	1	1	2	4	9	1	2	1	1	2	1	1	0	0	0	1	0	1	0
	1	1	0	0	0	1	0	0	0	0	1	1	3	4	2	1	1	0	1	4	0	1	0	0	0	1	0	1	0
	1	1	0	0	0	0	0	0	0	1	0	1	2	0	3	1	2	1	1	1	1	1	0	0	0	0	0	1	0
	2	1	0	0	0	0	0	0	0	1	1	1	2	0	5	1	1	1	2	4	1	1	1	0	0	1	0	1	0
	1	0	0	0	0	0	0	1	0	1	1	1	3	0	1	1	2	1	1	2	1	1	0	0	0	1	0	1	0
	1	0	0	0	0	1	0	1	0	1	1	1	2	5	3	1	2	1	1	2	1	1	0	0	0	1	0	1	0
	1	0	1	1	1	0	0	0	0	0	0	1	2	3	5	1	2	1	1	2	1	1	1	0	0	0	0	1	0
	3	1	0	0	0	0	0	0	0	0	1	1	2	0	9	1	1	1	2	2	1	1	0	1	0	0	0	0	0
	0	0	1	0	0	0	0	0	0	1	1	1	3	1	9	1	1	0	1	5	0	1	0	0	1	0	0	0	0
	1	0	0	1	0	0	0	0	0	0	1	1	2	9	9	1	1	1	1	3	1	1	1	0	0	0	0	1	0
	2	0	1	1	1	0	0	0	0	0	1	1	2	0	9	1	1	1	1	3	0	1	1	0	0	0	0	1	0
	2	0	0	0	1	0	0	0	0	1	1	1	1	2	2	2	1	1	1	2	1	1	1	0	1	0	0	0	0
	1	0	0	0	0	0	0	0	1	1	0	1	1	0	8	1	1	1	1	3	1	1	1	0	1	0	0	1	0
	1	0	0	0	0	0	0	0	1	1	0	1	1	0	8	1	1	1	1	3	1	1	1	0	1	0	0	1	0
	1	0	0	0	0	0	0	0	1	1	0	1	1	0	8	1	1	1	1	3	1	1	1	0	1	0	0	1	0
	1	0	0	0	0	0	0	0	0	1	0	1	1	0	8	1	1	1	1	3	1	1	1	0	1	0	0	1	0
	0	1	0	0	0	0	0	0	0	1	0	1	1	6	6	1	1	1	1	2	0	1	0	0	0	0	0	1	0
	1	1	0	0	0	0	0	0	0	0	0	1	2	0	9	1	0	1	2	1	1	1	0	0	0	0	0	1	0
	1	1	0	0	0	0	0	0	0	0	0	1	1	0	9	1	1	1	1	1	1	1	0	0	0	0	0	1	0
	1	0	1	0	0	0	0	0	0	1	0	1	1	2	5	1	2	1	1	2	1	1	1	0	1	1	0	0	0
	1	0	1	0	0	0	0	0	0	1	0	1	1	2	5	1	2	1	1	2	1	1	1	0	1	1	0	0	0
	1	1	0	0	0	0	0	0	0	1	1	2	2	0	2	1	2	0	2	2	1	1	0	0	0	0	0	0	0
	2	2	1	1	0	0	0	0	0	0	1	1	2	2	2	1	2	0	1	5	2	0	0	0	0	0	0	0	0
	2	1	0	0	0	0	0	0	0	1	0	1	3	2	3	2	2	0	2	5	1	1	0	0	0	1	0	0	0
	2	1	0	0	0	0	0	0	0	1	0	1	3	3	3	1	2	1	2	5	1	1	0	0	0	1	0	0	0
	2	0	1	0	0	0	0	0	0	1	1	1	1	3	1	1	1	0	1	5	0	1	0	2	0	0	0	1	0
	2	0	1	0	0	0	0	0	0	1	0	1	3	2	0	1	1	0	1	5	0	1	0	1	0	0	0	0	0
	1	0	0	0	0	0	0	0	0	1	0	1	2	0	2	1	2	1	2	2	1	1	0	1	0	0	0	0	0
	[illegible]	1	0	0	0	0	0	0	0	1	0	1	1	2	4	1	1	1	2	2	1	1	1	0	0	0	0	0	0
	1	0	1	0	0	0	0	0	0	1	1	1	3	2	0	1	1	1	2	2	1	1	0	0	0	1	0	0	0
	[illegible]	0	1	0	0	0	0	0	0	1	1	2	3	1	2	1	2	1	2	2	1	1	0	0	0	0	0	1	

A

...O SPECIFIC ENVIRONMENT QUESTIONS

...TMENT TO ADAPTIVENESS / ...ANT ADAPTIVE PERSONALITY / RAPID SIZE CHANGE / MISSION CHANGE / ORGANIZATION BY TASKS OR PROJECTS / COMPETITION TO SURVIVE / NOT ADAPTIVE / SIGNIFICANCE OF COMPETITION / ADAPTIVE CONTROL PRESENT / WITHIN AUTHORITARIAN ORGANIZATION / IMPORTANCE OF COMMITMENT / ADAPTIVENESS DECREASES / CONSENSUS-COLLABORATION / LONG PERSONAL ASSOCIATION / STRONG TECHNICAL INSIGHT / ATTENTION FOCUSED ON GOALS / SUPER-PERSUASIVE PERSONALITY / NOT CONSENSUS-COLLABORATION / INFORMAL EXP. / SPONSOR CONCEPTION / PROMOTER-CONCEIVER RELATIONSHIP / D.O.D. RESISTS INNOVATION / D.O.D. AUTHORITARIAN / LAB. DIR. REP. / R+D RELATIONSHIP OF GROUP / OUTSTANDING CONTRIBUTOR REPUTATION / CONCEIVERS INVOLVED IN EXECUTION / EXCEPTIONAL PERSONAL / STATE OF ART CHANGE / INTERDISCIPLINARY STIMULATION / DELAY AFTER COMPLETION / PAPER BRIDGE / HUMAN BRIDGE / TIMING

47	48	49	50	16	18	08	15	14	10	37	38	39	41	42	04	29	34	11	13	20	35	33	51	17	32	36	52	53	54	23-24
0	0	0	0	1	1	2	1	0	1	0	0	0	0	1	2	1	1	1	0	4	0	0	1	0	1	0	5	0	1	07
0	0	0	0	1	1	2	1	0	1	0	1	1	0	0	0	1	1	1	1	4	1	0	1	1	1	1	0	0	1	01
0	0	0	0	1	1	2	1	0	1	1	0	0	0	0	1	3	1	0	2	4	1	1	1	0	0	1	8	0	1	05
0	0	0	0	1	1	2	1	0	1	0	1	0	0	0	1	3	1	0	2	4	1	0	1	0	0	1	6	0	1	04
0	0	0	0	1	1	2	1	0	1	0	1	0	0	0	1	3	1	0	2	4	1	0	0	0	0	1	0	0	1	10
0	0	0	0	1	1	2	1	0	1	0	1	0	0	0	1	3	1	0	2	4	1	0	1	0	0	1	5	0	1	02
0	0	0	0	2	1	2	1	0	1	0	1	0	0	0	1	3	1	0	2	4	1	0	1	0	0	1	2	0	1	02
0	0	0	0	1	1	2	1	0	1	1	1	1	0	0	1	3	1	2	2	4	1	0	1	0	1	1	8	0	1	07
0	0	0	0	1	1	2	1	0	1	1	1	0	0	0	1	3	1	2	2	4	1	0	1	0	0	1	7	0	1	08
0	0	0	0	1	1	2	1	0	1	0	0	1	0	0	1	3	1	2	2	4	1	0	1	0	0	1	1	0	1	07
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0	0	0	0	1	1	2	1	1	1	1	0	1	0	0	1	1	0	0	0	4	1	1	1	0	0	1	1	0	1	01
0	0	0	0	1	0	1	1	2	0	0	0	0	0	2	1	1	1	1	1	2	0	1	.	1	1	0	9	0	0	08
0	0	0	0	1	1	2	1	0	1	1	0	0	0	0	1	1	1	0	0	4	1	0	1	0	0	0	0	1	1	99
0	0	0	0	2	1	2	1	0	1	1	1	0	0	0	1	1	0	0	1	4	1	1	1	0	0	0	0	1	0	98
0	0	0	0	1	1	2	1	0	1	1	1	1	0	0	1	1	0	1	1	4	1	1	0	0	0	1	1	1	0	01
0	0	1	0	1	1	2	1	1	1	1	0	0	0	0	1	1	1	1	0	2	1	1	1	0	0	0	1	1	1	01
0	0	1	0	1	1	2	1	1	1	1	0	0	0	0	1	1	0	1	0	2	1	1	0	0	0	0	1	0	0	01
0	0	1	0	1	1	[illegible]	1	1	1	1	0	0	0	0	1	1	1	0	0	2	1	1	1	0	0	0	0	0	1	03
0	1	1	0	1	1	1	1	2	1	1	0	1	0	0	1	1	1	0	2	4	1	1	1	0	0	0	0	1	1	01
0	0	0	0	2	1	2	1	0	1	1	0	0	0	0	1	1	1	1	2	2	1	0	1	0	0	0	0	1	1	98
0	1	0	0	1	1	1	1	2	1	0	1	1	0	0	1	1	0	1	1	4	1	1	0	0	0	1	0	1	0	99
0	0	0	1	2	1	2	1	2	1	0	0	1	1	0	1	1	1	0	2	4	1	1	1	1	1	1	1	0	1	98
0	1	0	0	2	1	1	1	2	1	0	1	0	0	0	1	1	0	0	1	2	0	1	1	0	0	0	7	1	1	09
0	0	0	0	2	1	2	1	0	0	0	0	0	0	2	1	1	1	1	0	3	0	1	1	0	1	1	1	1	1	04
0	0	0	0	1	1	2	1	0	1	0	1	1	0	0	0	1	1	2	1	4	1	0	1	0	1	1	0	0	1	99
0	0	0	0	2	1	2	0	1	1	0	0	1	0	0	1	1	1	0	0	2	[illegible]	1	1	0	1	1	5	0	0	04
1	0	0	0	2	1	2	1	2	1	0	1	1	0	0	1	0	0	0	2	4	1	0	1	1	2	0	0	1	1	99
1	0	0	0	0	1	2	1	1	1	0	1	1	0	0	1	0	1	1	0	4	1	0	1	0	2	1	0	1	1	00
0	0	0	0	1	1	1	1	1	1	0	0	0	0	1	2	1	1	1	2	4	1	1	1	0	0	0	0	0	1	96
0	1	1	0	1	1	2	1	1	1	0	1	1	0	0	1	1	1	0	0	4	1	1	1	1	0	1	2	1	1	04
0	1	1	0	1	1	2	1	1	1	0	0	1	0	0	1	1	1	0	0	4	1	1	1	1	0	1	0	1	1	03
0	1	1	0	1	1	2	1	1	1	0	1	1	0	0	1	1	1	0	0	4	1	1	1	1	1	1	1	1	1	04
0	1	0	0	2	0	2	0	0	2	0	0	0	0	2	1	1	0	0	2	2	1	1	1	0	0	0	5	1	1	05
0	1	0	0	2	1	2	1	0	1	1	1	1	0	0	1	1	1	1	1	2	1	0	1	0	0	1	4	1	0	09
0	1	1	0	1	1	2	1	1	2	0	0	0	0	2	1	1	1	0	0	2	1	1	1	0	0	1	1	1	1	05
0	1	1	0	1	1	2	1	1	2	0	0	0	0	2	1	0	1	0	0	2	1	1	1	1	0	1	3	1	1	07
0	1	0	0	1	1	2	1	0	1	1	0	0	1	0	1	1	1	0	2	4	1	0	1	0	0	1	3	1	1	03
0	0	0	0	1	1	1	0	2	1	1	0	0	0	0	0	1	1	0	1	2	0	0	1	0	1	1	0	1	0	97
0	0	0	0	1	1	1	1	1	1	0	0	1	0	0	1	1	1	0	0	3	0	0	1	0	0	0	2	1	1	03
0	1	0	0	2	1	2	0	1	1	1	0	0	1	0	1	1	1	0	2	4	1	0	1	0	1	1	3	1	1	03
0	1	0	0	1	1	2	1	0	1	1	0	0	1	0	1	1	1	1	2	4	1	1	1	0	0	1	0	1	1	02
0	0	0	0	2	1	2	1	0	1	0	1	0	1	0	2	1	1	0	1	2	1	0	1	0	0	0	0	1	1	97
0	1	0	0	1	1	2	1	0	2	0	0	0	0	2	1	1	0	0	1	3	1	1	1	0	0	0	0	1	1	00
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0	1	0	0	1	1	2	1	0	2	0	0	0	0	2	1	1	0	0	1	3	1	1	1	0	0	0	0	1	1	00
0	1	0	0	1	1	2	1	0	2	0	0	0	0	2	1	1	0	0	1	3	1	1	1	0	0	0	0	1	1	00
0	1	0	0	0	1	2	1	1	1	0	0	1	0	0	1	3	1	0	2	3	1	0	0	0	1	0	3	1	0	04
0	1	1	0	0	1	2	1	1	2	0	0	0	0	2	1	1	1	1	2	3	1	0	1	0	1	1	2	1	1	05
0	1	0	0	1	1	2	1	0	1	1	0	1	0	0	1	1	1	1	2	4	1	0	1	0	1	0	4	1	1	04
0	0	0	0	2	1	2	1	1	1	1	1	1	1	0	1	1	1	0	0	4	1	0	1	0	1	0	2	1	1	08
0	0	0	0	2	1	2	1	1	1	1	1	1	1	0	1	1	1	0	0	4	1	0	1	0	1	0	2	1	1	08
0	0	1	0	1	1	2	0	1	1	0	0	0	1	0	2	3	1	0	1	3	0	1	1	0	0	1	2	0	1	98
0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	1	2	2	1	1	2	2	2	2	0	2	2	2	2	2	04
0	0	0	0	1	1	2	1	0	1	1	0	0	0	0	1	3	1	2	2	4	1	0	0	0	0	1	4	0	1	03
0	0	0	0	2	1	2	1	0	3	0	0	0	0	0	1	3	1	2	2	4	0	0	1	0	0	1	3	0	1	02
0	1	0	0	1	1	2	1	0	2	0	0	0	0	2	1	0	1	1	1	4	1	0	1	0	0	1	0	0	1	03
0	0	0	0	1	1	2	1	0	2	0	0	0	0	2	1	1	1	1	1	3	1	0	1	0	0	1	3	0	1	00
0	0	0	0	1	1	2	1	0	1	0	0	0	0	0	1	3	[illegible]	2	2	3	1	1	1	0	0	1	7	0	1	02
0	0	0	0	1	1	2	1	0	1	0	1	0	0	0	1	3	1	2	2	4	1	1	1	0	0	1	1	0	1	05
0	0	0	0	1	1	2	1	2	1	1	0	0	0	0	1	1	1	0	0	2	1	0	1	0	0	1	3	0	1	00
0	1	0	0	1	1	2	1	2		1	0	0	0	0	2	3	0	2	2	2	0	1	1	0	0	1	7	0	1	02

B

TABLE E-2 DISTRIBUTION OF A

	CODE	COST EFFECTIVENESS	RISK STRATEGY	INVEST IN FIELDS	INVEST IN LABORATORIES	INVEST IN MEN	INVEST IN EVALUATION WORK	ALLOCATE DISCRETIONARY FUNDS	FORCE BY W/S DEVELOPMENT	FORCE BY REQUIREMENTS	CLEAR TRANSITION	PROGRESS IRREGULARITY	THREE ELEMENTS ESSENTIAL TO RXD	ELEMENT WHICH TRIGGERED EVENT	TRIGGER DELAY TIME	STATE OF ART DELAY IN YEARS	LOCUS	SPECIFIC NEED	WORK WAS STARTED PROMPTLY	D.O.D. OR PRIVATE FUND	(TYPE OF FUND)	LOCAL DECISION	ADAPTIVE ENVIRONMENT	PHILOSOPHIC COMMITMENT	SUPER GOALS	DOMINANT GOALS	R
		30	31	71	72	73	74	75	76	77	19	12	01	26	27	28	06	03	02	21	22	55	07	43	44	45	46
11 R Events	0	2		11	11	11	11	11	11	11	1	3			2		1		1			2			8	8	9
	1	2	8								10	8	10	2	6	1	10	5	10	3		9	11	11	3	3	2
	2	6	3										1	6	1	4		6		8	8						
	3													3	2	1					1						
	4																										
	5																				2						
	6															1											
	7															1											
	8																										
	9	1														3											
52 XD Events	0	2	33	35	47	49	47	50	48	49	22	19			19	4	1	2	9			10	1	29	40	41	39
	1	28	18	17	5	3	5	2	4	3	30	33	49	16	5	2	47	25	43	38	7	41	51	23	11	11	13
	2	19	1										3	22	10	10	3	25		-14	28	1			1		
	3	2												14	6	5	1				6						
	4														6	4					5						
	5														2	6					6						
	6														1	1											
	7																										
	8															4											
	9	1													3	16											
63 R and XD Events Together	0	4	33	46	58	60	58	61	59	60	23	22			21	4	2	2	10			12	1	29	48	49	48
	1	30	26	17	5	3	5	2	4	3	40	41	59	18	11	3	57	30	53	41	7	50	62	34	14	14	15
	2	25	4										-4	28	11	14	3	31		22	36	1			1		
	3	2												17	8	6	1				7						
	4														6	4					5						
	5														2	6					8						
	6														1	2											
	7															1											
	8															4											
	9	2													3	19											

A

OF ANSWERS TO SPECIFIC ENVIRONMENT QUESTIONS

ENT / COMMITMENT TO ADAPTIVENESS / GOALS / DOMINANT ADAPTIVE PERSONALITY

RAPID SIZE CHANGE 46	MISSION CHANGE 47	ORGANIZATION BY TASKS OR PROJECTS 48	COMPETITION TO SURVIVE 49	NOT ADAPTIVE 50	SIGNIFICANCE OF COMPETITION 16	ADAPTIVE CONTROL PRESENT 18	WITHIN AUTHORITARIAN ORGANIZATION 08	IMPORTANCE OF COMMITMENT 15	ADAPTIVENESS DECREASES 14	CONSENSUS-COLLABORATION 10	LONG PERSONAL ASSOCIATION 37	STRONG TECHNICAL INSIGHT 38	ATTENTION FOCUSED ON GOALS 39	SUPER-PERSUASIVE PERSONALITY 41	NOT CONSENSUS-COLLABORATION 42	INFORMAL EXP. 04
9 2	11	11	11	11	10 1	11	11	11	11	11	8 3	3 8	7 4	11	10 1	2 8 1
39 13	50 2	30 22	41 11	51 1	3 35 14	3 49	1 7 44	5 47	22 21 9	3 38 10 1	31 21	38 14	33 19	44 8	39 1 12	2 46 4
48 15	61 2	41 22	52 11	62 1	3 45 15	3 60	1 7 55	5 58	33 21 9	3 49 10 1	39 24	41 22	40 23	55 8	49 2 12	4 54 5

SPONSOR CONCEPTION 29	PROMOTER-CONCEIVER RELATIONSHIP 34	D.O.D. RESISTS INNOVATION 11	D.O.D. AUTHOR ARIAN 13	LAB. DIR. RE 20	R+D RELATIONSHIP OF GROUP 35	OUTSTANDING CONTR ACTOR REPUTATION 33	CONCEIVERS INVOLVED IN EXECUTION 51	EXCEPTIONAL PERSONAL 17	STATE OF ART CHANGE 32	INTERDISCIPLINARY STIMULATION 36	DELAY AFTER COMPLETION 52	PAPER BRIDGE 53	HUMAN BRIDGE 54
3 8	11	6 2 3	1 2 8	11	1 10	10 1	1 10	10 1	7 4	1 10	3 1 1 2 1 1 2	11	11
4 40 1 7	14 37 1	30 16 6	17 17 18	16 11 25	8 43 1	21 30 1	6 45 1	45 7	36 13 3	22 29 1	20 9 7 7 3 2 3 1	18 33 1	9 42 1
4 43 1 15	14 48 1	36 18 9	18 19 26	16 11 36	9 53 1	31 31 1	7 55 1	55 8	43 17 3	23 39 1	23 10 8 7 3 4 1 4 2 1	29 33 1	9 53 1

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